READABILITY OF BRAILLE
AS A FUNCTION OF THREE SPACING VARIABLES
A REPORT ON AN IN VESTIGATION BY

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A Report of an Investigation Done Jointly With
the American Printing House for the Blind
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The following were in their offices in Leroy Building
and it should have an additional floor:

Judge T. Perry, Attorney at the Criminal Courts
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A. C. Hall, Secretary of the Criminal Courts
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E. G. Sampson, Clerk Attorney at the Civil Courts
for the State.

William Dudley, Treasurer of the Odd Fellows for
the State.

Pauline Clemmons, Secretary to the Vice Consul
for the State.

A. A. Wood, Superintendent of the Colored Training
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Robert Dudley, Secretary, Notary Public and Clerk for the
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Examiner for the State.

Jesse Ford, Notary Public and Secretary of the Criminal
Courts for the State.

At all of the above offices, the building was well lighted
and

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AN EXPLANATORY NOTE

The following report consists of two separate investigations, one a study of the readability of Braille as a function of three spacing variables using school children as subjects and the second, a study of the readability of Braille as a function of the same Braille spacing variables with adult readers. The report of the first study is more detailed than the second. The kinds of analyses were essentially alike in both studies and the rationale for their use and interpretations of the particular statistics employed is much more fully described in the report of the first investigation. This is especially true for the Alexander trend analysis, which also turned out to be the most sensitive statistical tool.

READABILITY OF BRAILLE AS A FUNCTION OF THREE SPACING VARIABLES

HISTORICAL BACKGROUND

The purpose of this investigation is to determine, within limits, those spacing values of Braille material which permit greatest readability by blind readers. The spacing values in question are the distance between dots within the Braille cell, the distance between Braille cells, and the distance between Braille lines. A short resume of the history of reading systems for the blind will probably lead to a clearer understanding of the problem.

Line-Type Systems. The earliest forms of reading material for the blind were those employing letters of the Roman alphabet. Various methods were devised and tried out, although the most frequent was that of carving letters out of wood. The blind read this material tactually as early as the fourth century. Modifications of the shape of the letters in the Roman alphabet were later advanced with little improvement in the reading system. [1]

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1. Harry Best, Blindness and the Blind, 1934, P. 403-405.

An accidental discovery during the latter part of the eighteenth century paved the way for the durable system of reading for the blind.[2] A student at the Paris School for the Blind accidently felt the outlines of the letter, 'o', which had been strongly impressed upon a sheet of paper. Following the discovery that raised print was perceptible to the touch of the fingers, Valentin Hauy, an instructor of the above student, initiated the first studies on the legibility to the blind of embossed characters. After trying various types of letters, he selected the Roman alphabet and embossed many books for the blind. At the close of the eighteenth century the pioneers in the field continued to build their systems on the assumption that the blind could best perceive through the sense of touch the same form of characters that was perceived by the sighted.

Arbitrary Non-Dot Systems. During the nineteenth century it was realized that either the Roman Letter would have to be further simplified or an entirely different style of character based on some arbitrary principle would have to be employed.[3] The first widely accepted arbitrary non-dot system was devised

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2. Ralph V. Merry, Factors Involved in Tactile Reading, 1928, P. 1.

3. Harry Best, Blindness and the Blind, 1934, P. 408-409

by Lucas of England in 1837, who designed a type of shorthand alphabet. The basic characters consisted of four lines, one vertical, one horizontal, and two oblique.

Another arbitrary non-dot system was devised in 1847 by a blind man, Dr. William Moon. His system consisted of highly modified Roman capital letters. Nine letters of the alphabet were but little changed, thirteen were simplified, and four new characters were added. The system can be read by the return line method from left to right and back from right to left.

Moon's system has been reported to be very easily learned, particularly by adults, and is still very much in use, although it is very bulky and slowly read and cannot be written by the blind.[4]

Dot Systems. During the first quarter of the nineteenth century Charles Barbier of Paris, France, constructed a dot system of reading for the blind. His system consisted of groups of dots in cells containing two vertical columns of six points each. The characters were selected by phonetic principles, each character representing a certain sound. Best [5] states that the system was not acceptable for general

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4. Ralph V. Merry, Factors Involved in Tactile Reading, 1928, P. 5.

5. Harry Best, Blindness and the Blind, 1934, P. 410-411.

use as the cell was too large for immediate perception and it necessitated a considerable waste of space.

In 1829, Louis Braille, a blind instructor at the Paris School for the Blind, made the necessary modifications. His cell consisted of two vertical columns of three dots each. Sixty-three characters could be represented by one or more dots in various combinations. The customary orthographic stucture was substituted for the phonetic arrangement of Barbier's system. [6] The simplest possible combinations of dots were given to the first ten letters (a-j), employing all combinations of the first and second rows. For the letters k through t a dot in the bottom row at the left was added to each of the foregoing letters, and for the letters u through z both dots in the bottom row were added. [7] This remains the basic code of present day Braille.

The Braille System was introduced into the Missouri School for the Blind in 1860. Abbreviations were devised in this country which stood singly for words of phrases of very frequent occurrence. This system was known as Grade 11, the original being Grade 1. It has also been referred to as English or British Braille. [8]

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6. Ibid.

7. Karl Burklen, Touch Reading of the Blind, (translated from the German by Frieda Kiefer Merry), 1932, P. 57.

8. Harry Best, Blindness and the Blind, 1934, P. 412.

At the close of the nineteenth century, two independent modifications of the Braille System instigated much debate and some experimentation on the best reading system for the blind. [9] The first modification was devised in 1868 by William Wait of the New York Institute for the Blind. This New York Point System, instead of being vertical in structure, was mainly horizontal and was two points high and one or more points long. The system was based upon the principle of frequency of recurrence; the most frequently used characters were composed of the fewest number of dots. This system was adopted in most of the schools for the blind. Ten years later Joel Smith rearranged Braille's system according to the principle of the frequency of recurrence, and this system, given the name American Braille, was also adopted in a number of schools for the blind in this country.

During this time there were two point systems in use by the blind in America. In 1900 a Tactile Print Investigating Committee was appointed by the American Association of Workers for the Blind. This later developed into the Uniform Type Committee.[10]

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9. Ibid.

10. Report of the Uniform Type Committee, Outlook for the Blind, 1908.

This committee was to compare the several existing systems and to recommend a system for universal adoption. Much of their selection was based on the judgements of their members, although there were some investigations using small numbers of subjects.

Their finding concerning readability as a function of the number of dots was that "Within limits, a system using few dots can be read more rapidly and accurately than one using many dots". [11] Burklen [12] states that readability is more a function of the pattern or form of the dots than it is of the number of dots, a character with good geometric pattern is more easily read than one with a fewer number of dots. For example, in his experiment, the character representing the letter 'g', composed of four dots (: :), was found to be more readable than any of the characters composed of only two dots.

The committee also reported that, " A system using few dots can be written with the Hall Braille Writer more rapidly and accurately than one using many dots" [13]

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11. Ibid.

12. Karl Burklen, Touch Reading of the Blind, 1932, P. 18.

13. Report of the Uniform Type Committee, Outlook for the Blind, 1908.

In addition they compared New York Point and American Braille on readability as a function of the number of dots in the vertical column. Their findings showed that if the number of dots was held constant, the system using as many as three points high could be as easily read as one employing only two points.

Another investigation by this committee concerned whole-word and part-word signs. They stated that whole-word signs which did not introduce a question as to the level of a character in the line facilitated reading, and otherwise was a hindrance. The effect of the part-word signs was not so clearly indicated.

The next report of the committee was presented in 1909. [14] During the two years, they had repeated some of the studies of 1907, employing a larger number of subjects. Their findings were essentially the same. One additional investigation demonstrated that vertical signs were more legible than horizontal signs. The committee reported similar conclusions in 1911, with one additional study. [15] This investigation was of the

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14. Report of the Uniform Type Committee, Columbus, 1909 Convention, American Association of Workers for the Blind.

15. Report of the Uniform Type Committee, June, 1911.

fourth base characters in New York Point. They stated that the results of this study were uncertain because the experimental reading material, composed of proper names, was too difficult for their subjects to read.

In 1913, the committee reported on a study which directly compared the three selected systems. [16] Subjects had read three selections in British Braille, American Braille, and New York Point. Their findings showed that British Braille was most easily read, and New York Point was least easily read.

In 1915, the committee proposed a modified system which they called the Standard Dot System. This system consisted of a combination of the features of British Braille, American Braille, and New York Point.[17] This was accepted officially the following year, although it was not actually adopted. The British refused to accept so drastic a change, and the matter terminated in 1917, when the American workers accepted the British Braille.[18] They did incorporate a few changes under the name of Revised Braille, which was to be known as Grade One and a Half because it fell intermediate between Grade One and Grade Two of the English System.

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16. Uniform Type Committee, Fourth Biennial Report, Jacksonville, June, 1913.

17. Uniform Type Committee, Convention of Workers for the Blind, Berkeley, California, 1915

18. Report of the Commission on Uniform Type for the Blind, Portland, Maine, June, 1917.

In 1932, another agreement was effected which consisted of a slight modification of Grade Two Braille.[19] This final revision has been given the name Standard English Braille and is being used in the schools today.

Related Studies. Before the Standard System was completed, problems were introduced concerning which dimensions should be used in the printing of the standard code. It was desired that the printing houses for the blind seek uniformity in their printed material. Such variables as spacing between dots within Braille cells, spacing between Braille cells and spacing between lines needed to have fixed values to attain universal agreement.

The Uniform Type Committee, while working on the problem of the best code, also studied to a limited degree, the spacing variables. In this study they took three lists of the same words differently arranged. All subjects read each list in American Braille with each spacing arrangement. "One list was printed with the usual block spacing, one with the Uniform New York Point interval between characters and one with a closer varying interlitteral spacing."[20] Many of the subjects had no previous experience with either form of close spacing, so the results of their experiment are questionable. However, they concluded that their study "would seem to indicate a small loss in legibility, and considerable economy in space" with the close forms of spacing.

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19. National Institute for the Blind, Standard English Braille, 1932.

20. Uniform Type Committee, Fourth Biennial Report, Jacksonville, June, 1913.

By 1920 it was still debatable as to what was the most suitable specifications of type for reading. To this end, a study of spacing was made by the Commission on Uniform Type.[21] Their experiment employed eight lists, four of words and four of letters in four different scales of type (eighty simple words and three hundred letters). All subjects read all lists in a different order. The four scales used were as follows:

Scale of Type		Dots	Cells	Lines
Commission Scale		.090	.250	.398
Close-Letter Scale		.090	.218	.380
Close-Line Scale		.090	.250	.265
Reduced Scale	Laterally	.082	.218	.365
	Vertically	.072		

The total number of seconds taken and the total number of errors made by all readers on each of the eight sheets was recorded. An estimate of both time and accuracy was made, introducing a penalty of five for every error. From these scores the relative efficiency for each scale of type was computed. Their results showed that the Commission Scale was the most desirable and this was accepted as the standard, the exception being a change in the line spacing from .398" to .400".

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21. Fifth Report of the Commission on Uniform Type for the Blind, 1920.

In 1927, some data were gathered on the most desirable height of dot.[22] Prior to that time the question of the proper height of dot in Braille books was determined by the preference of the publishers. Many felt that the dots should be made as high as possible. without breaking through the paper. In most of the books published, the dots ranged from .026" to .030" in height. This investigation compared dots of .025", .022" and .018" in height. It was found that the dots of .022" were superior to either of the extreme heights (.025" or .018"). Few embossers used a dot lower than .025", yet it was shown that lower dots are superior.

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22. Kathryn E. Maxfield, The Blind Child and His Reading, 1928, P. 14.

RATIONALE AND PROCEDURE FOR PRESENT STUDY

It is apparent that there has been very little systematic experimentation on the readability of Braille as a function of the size and spacing specifications. The three spacing variables, spacing between dots within Braille cells, spacing between cells, and spacing between lines, were selected for the present investigation.

At present there is disagreement as to the most suitable values of the spacing variables for readability. Regarding the spacing between Braille dots, Kunz states that when the interval between the dots was reduced in France to less than three millimeters "the limits of the sense of touch, and of legibility had been exceeded... For the simultaneous apprehension of several obtuse points by the blind, the distance between the points should be three millimeters," [23] However, Burklen states, "The usual size of the characters (7 mm. high by 4.5mm. wide) may be considered satisfactory as an upper but not as a lower limit. The most useful spacing of the dots from one another lies between 2 and 3 mm., but this is still to be determined through intensive research. A reduction of Braille type below the present measurements seems possible."[24]

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23. M. Kunz, The Physiology of the Blind, 1908, P. 6

24. Karl Burklen, Touch Reading of the Blind,1932, P. 52

Maxfield has suggested that it might be advantageous to adopt a wider line spacing for teaching blind beginners, but stated, "as there is no conclusive evidence for or against the use of a wider line spacing," that this would depend on the decision of the teachers.[25]

In the present study, three values of each of the spacing variables were selected to be read in all possible combinations. The standard values and one value greater than the standard and one less than the standard were employed for each of the spacing variables, with the exception of cell spacing in which both added values are less than the present standard. The standard spacing is as follows:

Between dots within Braille cells	.090"
Between Braille cells	.160"
Between Braille Lines	.220"

The conventional method of measuring the distance between Braille cells and lines differs from the method used in this investigation. For instance, the distance between Braille cells is usually cited as the distance between corresponding dots in adjacent cells or the distance between dot one in adjacent cells. In this study the distance cited is that between dot four in one cell and dot one in the adjacent cell.

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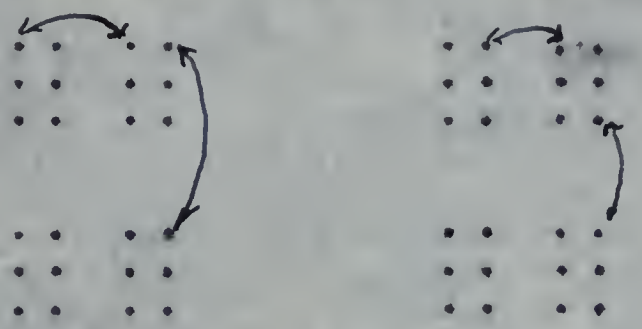
25. Kathryn E. Maxfield, The Blind Child and His Reading, 1928, P. 43.

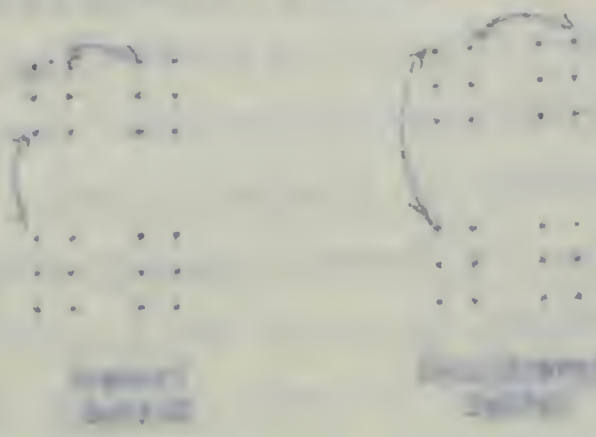
Likewise the distance between lines is usually cited as that between corresponding dots in adjacent lines, whereas the distance referred to in the present study refers to the distance between the two closest dots: ie, dot three and dot one. The following diagram illustrates the two methods:



Conventional Method

Present Method

The experimental values selected for dot spacing within cells was .080", .090", and .100". The minimum value at which the dots can be spaced is .080" because the dot bases would overlap at a smaller value. The upper value was selected for experimentation somewhat arbitrarily. The spacing values between Braille cells was .123", .140", and .160". These values also were chosen somewhat arbitrarily. However, it was felt that the lowest value should be considerably greater than the distance between dots within Braille cells. Both added values were less than the standard because it was felt that any increment in readability which might be added by using wider spacing would have been cancelled out by the increase in the additional space through which the fingers must move. The final determination of the values was based on the number of Braille letters perline when the within cell spacing was standard (.090"). This gave the above values and the corresponding number of letters per line was forty-two, thirty-nine, and thirty-six respectively.



The values chosen for line spacing were .163", and .220". and .300". These were again somewhat arbitrarily chosen, but they permit twenty-nine, twenty-five and twenty-one lines per page respectively, when the other spacing variables are standard.

The three values of each of the three variables were combined in all possible ways, making a total of twenty-seven combinations.[26]

An attempt was made to hold the height of the dots constant at .015". 247 dots were randomly selected from nineteen of the twenty-seven experimental sets of materials and their dots heights measured with an optical comparator. The mean height was .0155", the range was from .0123 - .0178.[27] The standard dot height is .017"; however, a height of .015" was employed to keep broken dots at a minimum. The standard base diameter is .060" but .055" allowed greater variation of the experimental variables.

Another deviation from standard Braille was made in the method of spacing the cells on the back of the page. The method used in standard embossing, which we shall call semi-interpointing, overlaps the space between the second and third rows of dots on the front page and extends two rows below. The material for present investigation was embossed with what we shall call full-interpoint, employing the space between the first and second rows of dots on the front page in addition to the space between the second and third rows.

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26. Appendix, I.
27. Appendix, VIII.

The reason for the use of full interpoint was to permit wider range of experimental line spacing values. The results of a previous study by the experimenters demonstrated that full-interpoint is read as easily and quickly as semi-interpoint.

Procedure. This investigation was done in two parts. In the first part the subjects were children and in the second part the subjects were adults. They are treated separately in this report. The following procedure and result sections are for the children only.

Each of the twenty-seven combinations of spacing variables was read by four subjects, requiring a total of 108 subjects. Although the use of more subjects would have been desirable, it was not practical to do so. The material was read by children from the State Schools for the Blind in Ohio, Kentucky, Indiana, Illinois, and Tennessee. Children in grades five through twelve were tested.

The reading material was from The Black Arrow by Robert Louis Stevenson.[28] This book had not been printed in Braille in America,[29] thereby providing unfamiliar reading material, but it is one that seems to be interesting to a wide age and intelligence range. The edition which was read was rewritten for easy reading by Carlin and Christ. A Flesch readability Analysis[30] was made on the book, and, according to the findings, it should be readable by children at or beyond the fifth grade level.

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28. Robert Louis Stevenson, The Black Arrow, adopted for easy reading by Carlin and Christ, 1947.

29. One subject had rea and English edition of the book, and several had read the talking book. All were discarded from the experimental study.

30. Rudolf F. Flesch, How to Test Readability, 1951.

Equating Study. Chapters twelve and thirteen from the book were selected for a preliminary reading ability test. These Chapters provided interesting episodes which could be understood independently of the rest of the book. This material was embossed in standard Braille. A standard set of instructions was given to all the groups reading the material.[31] As each group consisted of a separate grade in the school, the number of subjects in the groups varied. However, no more than nineteen children read the material simultaneously. All subjects were instructed to read as much of the material as possible without skipping words. There was a thirty minute reading period. They were told that they would be asked questions on the material they were to read. At the end of the specified reading time the amount read by each subject was recorded and the booklets were taken up. Their comprehension of the material was measured from a list of twenty questions of the multiple choice type. There was no time limit for answering the questions.

It was necessary to test 275 children in order to have a sufficient range of reading ability and number of scores for the experimental design. Measures were taken on the comprehension of the material and the average number of words per minute read by each subject. All children who did not answer at least fifty percent of the questions covering the amount of material read were discarded for further consideration. This excluded twenty-two children.

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31. Appendix, 2.

The scores of the remaining 253 children were placed in a frequency distribution and the distribution was divided into quartiles.[32]

Experimental Study. One subject from each quartile was selected for each of the twenty-seven cells of the design. The scores were selected in order to have the mean reading ability of the four subjects in each cell the same. A wide range of ability was included within each cell, but the range between cells was kept at a minimum. The particular scores within the quartiles were selected in such a fashion that the mean for each cell was seventy words per minute and the within cell range was approximately the same from cell to cell.[33]

Each group of four subjects read a different combination of the spacing variables. The American Printing House for the Blind compiled the twenty-seven different sets of material, only one of which approximated the present standard Braille. The characteristics of the material were checked and rechecked throughout the printing. The first eight chapters of The Black Arrow were read in the experiment.

In order to familiarize the subjects with the new type of Braille, they were asked to read for two fifty minute periods on successive days. In addition, any changes due to warm-up and fatigue effects could be determined. The instructions for reading the experimental material were essentially the same as in the preliminary reading test.[34] The subjects were asked to read the material as fast as they could without skipping, and told that they would be asked questions on the material they read when they had finished.

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32. Appendix, 3. 33. Appendix, 4. 34. Appendix, 5.

They were given thirty multiple choice questions on the material at the end of the second reading period. Any subject who failed to answer at least fifty percent of the questions on the material read was discarded from the study and another subject with a similar score was substituted. Twelve of the original 108 subjects selected to read the twenty-seven combinations were replaced by subjects with similar scores. These twelve original subjects were not used because of lack of comprehension of the material, or failure to follow instructions, or unavailability on the testing date.

The subjects read the experimental material in groups of four. The total number of words for the two reading periods was calculated for each subject. In addition, during the reading periods the time at the end of each page was recorded for each subject. These data were gathered in order to determine if there were any differences in the amount of fatigue produced by the various spacing combinations.

DISCUSSION OF RESULTS OF FIRST INVESTIGATION

Reading Rate -- Equating Material. Surprisingly enough, there is very little data on the reading rate of the blind. In an experiment by Burklen[35] fifty German subjects read material from a school text for one minute. The average reading speed for his subjects was sixty-six words per minute.

In the present study, the average number of words per minute read by the 275 subjects reading material with standard Braille specifications was sixty-eight. The length of the reading period was thirty minutes. However, a Flesch Readability Analysis showed that the material read in this study was readable at the fifth grade level. As 234 of the subjects were beyond the fifth grade, the material was probably read more rapidly than much that they ordinarily read. The average reading speed obtained for each grade level is shown in Figure 1.

As would be expected, the reading speed increases with grade level. However, the shape of the curve suggests three lengthy plateaus and two stages of improvement. There is no change from the fifth to the sixth grade, but there is an increase of twenty-three words per minute from the sixth to the seventh grade. Following this sharp rise in the curve there is little change for the next two grades, and then there is another increase of fourteen words per minute at the tenth grade with another plateau for the next two grades.

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35. Karl Burklen, Touch Reading of the Blind, 1932, P. 44-45.

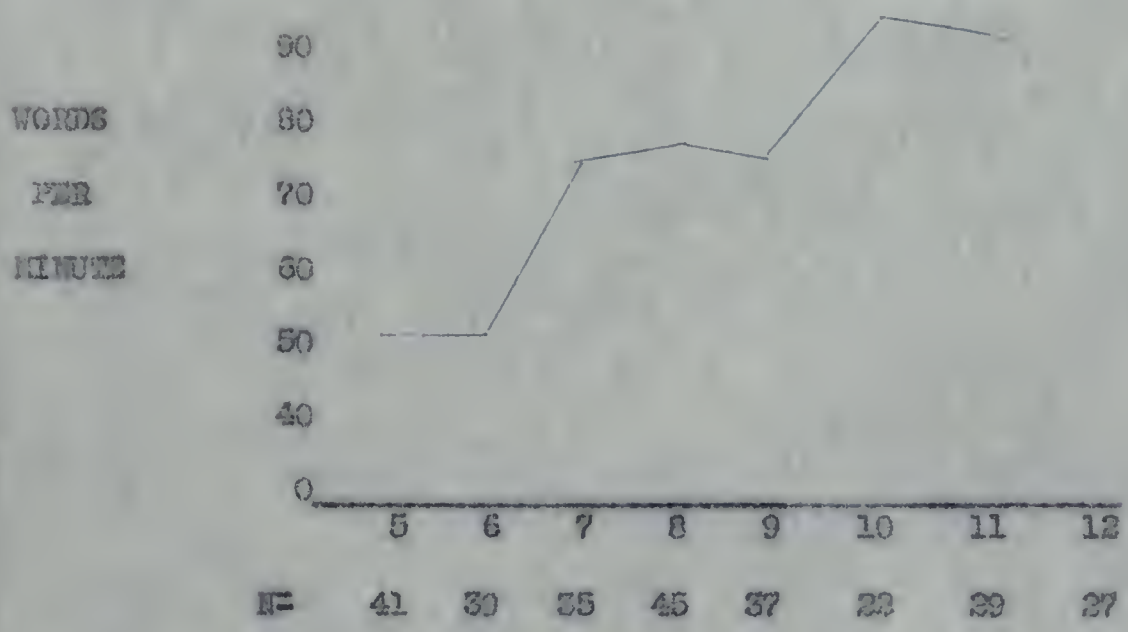

Figure 1. Average number of words per minute read at successive grade levels.

It seems then, as if there are long periods in which there is no apparent increase in reading rate. It is possible that the rapid increases from the sixth grade to the seventh grade and from the ninth to the tenth grade may be accounted for by poor readers dropping out of school at these levels. Their results should be of interest to the educators of the blind.

MEAN READING RATES FOR DOT, CELL, AND LINE SPACING.

Comparing the four scores of subjects who read particular combinations of Braille spacings would not be as meaningful as combining all subjects who read combinations which contained a particular value. For example, the dot spacing of .080" was included in nine different combinations, four subjects read each combination so there are thirty-six subjects who read Braille whose dot spacing was .080". Likewise, thirty-six subjects read Braille whose dot spacing was .090", and thirty-six subjects read Braille whose dot spacing was .100". In the same manner, subjects can be grouped for cell and line spacing. The means for each of these nine groups of thirty-six subjects are presented in Table 1.

Braille printed with .080", .090, and .100" space between dots was read at an average speed of 65.8, 73.3 and 71.8 words per minute respectively. It appears that the material employing dot spacing of .080" was not read as rapidly as that with .090" and .100". The latter differ by only one word per minute. The three mean number of words per minute for the material with different cell spacings are 72.8, 69.6, and 68.6 from the smallest spacing to the largest spacing. There seems to be little difference between the three means for cell spacing ,

MEAN READING RATES WITH SPECIFIC VALUES FOR BOTH READING PERIODS

DOT SPACING

	.080"	.090"	.100"
	71.0	68.2	73.0
	63.8	69.0	74.8
	68.3	69.0	63.0
	76.8	68.0	64.3
	60.0	60.0	74.5
	56.0	64.0	78.5
	62.0	82.0	70.0
	67.3	86.0	75.0
	66.5	93.5	74.0
Average	65.8	73.3	71.8

CELL SPACING

	.123"	.140"	.160"
	71.0	63.7	73.0
	69.0	68.3	63.0
	69.0	74.8	68.0
	76.8	68.3	56.0
	64.3	60.0	74.5
	62.8	60.0	64.0
	78.5	82.0	86.0
	70.0	75.0	67.3
	93.5	74.0	66.5
Average	72.8	69.6	68.6

LINE SPACING

	.163"	.220"	.300"
	71.0	73.0	66.0
	65.8	76.8	69.0
	77.3	60.0	60.0
	63.0	68.0	56.0
	69.0	78.5	74.5
	68.0	82.0	62.8
	64.3	67.3	70.0
	64.0	74.0	86.0
	66.5	93.3	75.0
Average	67.6	74.7	68.8

TABLE 1

The first three columns represent average words per minute for the three dot spacings, each of the nine numbers in the first column is the mean rate of four subjects. Thirty-six subjects read material whose dots within Braille cells were spaced at .080". This column represents, then, all subjects who read Braille whose dots were this far apart regardless of the specifications for between cells and between lines. The second column is the same for subjects whose dot spacing was .090", etc. The second three columns represent averages for cell spacing and the third three columns for line spacing.

but it is interesting that the material with the closest cell spacing (.123") was read more rapidly than the other two. The value of .123" places the Braille cells considerably closer than the present specification (.160").

Material printed with a line spacing of .163" was read at an average rate of 67.6, whereas the material with a .230" space between lines was read at an average of 74.7 words per minute, and the .300" spacing had a mean reading rate of 68.8. The material whose line spacings was .220" was read faster than the other line spacing of .163" or .300". A value of .220" also represents the present standard distance between lines.

From the above it appears that a combination whose dot spacing is either .090" or .100" and whose cell spacing is .123" and whose line spacing is .220" is superior. However, the differences between the means are not large and the following sections will be concerned with further statistical analyses of the data, without which no conclusions can be made.

Mean Reading Rate for Particular Combinations. The average number of words per minute read by each of the four subjects for the twenty-seven combinations is shown in Table II. The largest total increases in rate as compared to speed of reading the equating material were read by the four subjects reading with the values .090", .123", and .230" between dots, cells, and lines respectively.

The total number of words per minute increased by ninty-six for this group. It is interesting that this is the particular combination that was suggested as superior from the analysis of the combined data. However, most of the increase was contributed by the subject from the third quartile. This spacing combination consists of the standard values for dot and line spacing and the smallest value used in the study for spacing between Braille cells. The subjects reading the combination of the standard values for dot and cell spacing and the largest value of line spacing also showed a large increase in the number of words read. The total gain for this group was sixty-four words per minute. One subject reading this combination decreased one word per minute, and the other three gained in reading speed. The subjects reading the combination of the middle values of each of the three variables gained forty-eight words per mimute.

The largest decrease in reading speed was made by the group reading the combination of .080" - .160" - .300", having a total loss of forty-seven words per minute. A loss of forty-words per minute was made by the subjects reading .080" - .140" - .220" and the group reading .090"-.140"-.300". Only one subject in these three groups had an increase in reading speed, and this amounted to only three words per minute.

MEAN READING RATES FOR PARTICULAR COMBINATIONS

080-123-163-	080-140-300	090-140-163	090-123-300	100-160-220
32	36	30	29	34
50	49	61	59	75
68	69	76	86	86
134	101	106	102	97
284	255	273	273	292

100-140-163	100-150-163	090-123-163	080-140-163	080-123-220
42	29	24	69	72
59	51	62	63	63
86	38	76	65	62
112	84	114	76	110
299	252	276	273	307

080-140-220	090-160-220	090-140-300	080-160-300	100-123-163
28	27	24	29	38
61	58	42	58	45
58	84	84	58	67
93	103	90	79	107
240	272	240	224	257

100-160-300	080-123-300	100-123-220	090-160-163	090-140-220
41	40	48	48	40
70	44	54	43	50
61	72	55	60	74
126	95	157	105	164
298	251	314	256	328

100-123-300	090-160-300	080-160-220	100-140-300	080-160-163
55	53	43	45	38
78	44	47	51	33
55	117	67	85	80
92	130	112	119	115
280	344	269	300	266

100-140-220	090-123-220
34	30
63	63
84	177
115	104
296	374

Table II. Individual scores and group total for twenty-seven groups reading with different combinations of Braille Specifications.

Analysis of Variance -- Total Number of Words Read.

An analysis of variance[36] was made of the total number of words read for the two reading periods. The analysis is based on words per minute. As there was a large within-groups variance, no variable or interaction was found to be significant. The summary of the findings for the total number of words read is presented in Table III.

Source	df	SS	MS
Between Dots	2	1143	571.50
Between Cells	2	329	164.50
Between Lines	2	1081	540.50
Dots X Cells	4	1446	361.50
Dots X Lines	4	1002	250.50
Cells X Lines	4	949	237.25
Dots X Cells X Lines	8	1244	155.50
Within Groups	81	99774	1231.77
Total	107	106968	

Table III. Summary of Analysis of Variance: Total Number of Words

The within-groups variance more than doubles the amount of variance contributed by any of the spacing variables. Initially this large amount of variation was purposely introduced in the design as a control factor, and, in addition, as a basic criterion for the determination of the significant difference between the specific combinations. Any interaction that might exist between level of reading rate and the effect of the combination of spacing values was held constant for all of the combinations employed. With this design any difference between the groups which did not exceed the variance that existed between the individuals within a group would be attributed to chance.

36. E. F. Linquist, Design and Analysis of Experiments in Psychology and Education, 1953.

Mean Reading Rates for the First Fifty-Minute Reading Period. The means for the nine groups of four subjects were combined as in the analysis of the total reading rates to obtain an average reading rate for each of the specific values. The averages, based on thirty-six subjects, for each of the nine spacing values are presented in table IV.

The reading rate of the standard dot spacing (.090") exceeded the other two spacing values by a small amount. As in the total analysis, there seems to be little difference between the three means for cell spacing. The standard spacing value for distance between lines (.220") was read faster than the other two values, as in the total analysis. From this, it is suggested that initially the standard values of dot and line spacing are superior, and there is little difference between the three values of cell spacing.

Analysis of Variance--First Reading Period. An analysis of variance was made of the reading speeds at the end of the first fifty-minute period, with essentially the same findings as in the analysis of the total reading rates. The summary of the findings is given in Table V.

MEAN READING RATES WITH SPECIFIC VALUES DURING THE FIRST PERIOD

DOT SPACING

	.080"	.090"	.100"
	71.5	66.5	69.8
	65.3	64.5	73.0
	75.3	70.0	60.0
	83.3	66.8	58.8
	55.5	57.8	75.0
	55.8	63.3	71.5
	59.3	83.8	62.0
	66.5	76.8	72.8
	68.0	92.5	71.8
Average	66.4	71.3	68.3

CELL SPACING

	.123"	.140"	.160"
	71.5	65.3	69.8
	64.5	66.5	60.0
	70.0	73.0	66.8
	80.8	75.3	55.8
	58.8	55.5	75.0
	59.3	57.8	63.3
	71.5	83.8	76.8
	62.0	72.8	66.5
	92.5	71.8	68.0
Average	71.1	69.1	66.8

LINE SPACING

	.163"	.220"	.300"
	71.5	69.8	65.3
	66.5	80.3	64.5
	73.0	55.5	57.8
	60.0	66.8	55.8
	70.0	71.3	75.0
	75.3	83.8	59.3
	58.8	66.5	62.0
	63.8	71.8	76.8
	68.0	92.5	72.8
Average	67.6	73.2	65.4

Table IV. Mean Readings Rates for the first reading period of thirty-six subjects for each of the spacing values. The first three columns represent average words per minute for the three dot spacings, the second three columns are the averages for cell spacing and the third three columns for line spacing.

The within-groups variance, as in the total analysis, again doubles the variance for any of the spacing variables, and no significent differences were obtained.

Source	df	SS	MS
Between Dots	2	438	219.00
Between Cells	2	195	97.50
Between Lines	2	1173	586.50
Dots X Cells	4	896	224.00
Dots X Lines	4	1805	451.25
Cells X Lines	4	1687	421.75
Dots X Cells X Lines	8	1774	221.70
Within Groups	81	92912	1147.06
Total	107	100880	

Table V. Summary of Analysis of Variance: First Reading Period.

72.1	77.4	84.1
71.4	80.2	84.2
70.8	77.9	77.8
69.2	75.4	81.3
77.0	78.1	78.0
77.1	79.4	79.8
78.4	80.1	80.7
78.9	81.0	76.3
80.1	82.5	79.8
67.3	71.8	84.4

Table 17. Test location blocks the fiber-first reading during it fiber-rich cultivate for wood to the crowding volume. The first fiber volume movements overlap would station for the first leaf quality, the largest fiber volume in the pressure for will specialty and the outer tissue volume for life quality.

The physiology thickness, the fiber depth reduction.

Cells maintain the machines for use of the crowding production.

Soil or drought-tool deficiency have physical.

Account	Qty	Unit	Amount
Software Sales	1	499	499.00
Software Update	1	149	149.00
Support Class	1	1275	1275.00
Books & Media	4	89	356.00
Books & Media	4	1299	1299.00
Books & Class	1	1499	1499.00
Books & Class	1	1499	1499.00
Books & Class	1	1499	1499.00
Training Session	12	1299	15588.00
Total			25892.00

Table 9. Planning of Engineers at Volunteer Survey Training.

Mean Reading Rates for the Second Reading Period.

The analysis of the last fifty-minute period was made in order to determine any differences in final reading speed after practice with the specific spacing values. The combined averages for the nine spacing values are presented in Table VI. These averages are again based on the thirty-six subjects reading Braille with one specific value, regardless of the specifications of the other two values.

MEAN READING RATES WITH SPECIFIC VALUES DURING THE SECOND PERIOD

DOT SPACING

	.080"	.090"	.100"
	71.3	73.8	69.5
	73.0	68.5	85.5
	65.5	94.3	77.8
	66.8	69.8	76.3
	61.0	62.3	76.8
	64.3	80.8	76.5
	55.8	69.5	76.8
	68.5	64.3	66.3
	64.8	95.5	76.3
Average	65.6	75.4	75.7

CELL SPACING

	.123"	.140"	.160"
	71.3	66.8	55.8
	73.0	61.0	68.5
	65.5	64.3	64.8
	76.3	69.8	69.5
	68.5	62.3	64.8
	94.3	80.8	95.5
	69.5	76.3	76.8
	85.5	76.8	66.3
	77.8	76.5	76.3
Average	75.4	70.4	70.9

	LINE SPACING		
	.163"	.220"	.300"
	71.3	73.0	73.8
	68.5	85.5	65.5
	69.5	94.3	77.8
	69.8	64.3	66.8
	78.8	80.8	62.3
	61.0	79.0	76.8
	66.3	79.3	55.8
	59.8	69.5	76.3
	59.8	63.5	95.5
Average	68.0	76.5	72.2

Table VI. Mean reading rates for the second fifty-minute reading period of thirty-six subjects for each of the nine spacing values. The first three columns represent the average words per minute for the three dot spacings, the second three columns are the averages for cell spacing and the third three columns for line spacing.

The subjects reading with the spacing of .100" between dots gained an average of eight words per minute over their rate during the first reading period. An increase in reading rate was also obtained with the standard dot spacing (.090"), yet it was slightly inferior to the larger dot spacing during the second reading period.

The smallest cell spacing (.125") was read more rapidly than the other two values, and the standard distance between lines was again read at a higher speed. After practice with the material, those combinations with .100"-.123"-.220" in them were read more rapidly than any of the other values.

Analysis of Variance--Second Reading Period.

A separate analysis of variance was made of the reading rate for the last fifty-minute period, again, the results were essentially the same as in the first two analyses. However, the amount of variance contributed by the spacing between dots nearly equals that of the within groups. The summary table for this analysis is given in Table VII.

SOURCE	df	SS	MS
Between Dots	2	2375	1187.50
Between Cells	2	548	274.00
Between Lines	2	1317	658.50
Dots X Cells	4	319	79.75
Dots X Lines	4	1003	250.75
Cells X Lines	4	597	149.25
Dots X Cells X Lines	8	2775	346.87
Within Groups	81	115427	1425.02
Total	107	124361	

Table VII. Summary of Analysis of Variance: Second Reading Period

Reading Rate at Successive Intervals. In order to detect differences in reading rate as a function of practice with any particular combination, the total reading time of one-hundred minutes was separated into four reading periods, the first and second twenty-five minutes for the two days. The average words per minute read by each subject for the twenty-seven combinations was computed for the four periods. However, the reading rates for the four subjects reading a particular combination varied to such an extent that it was necessary to present the data in some other manner. It seemed more meaningful to present the data in terms of the amount of deviation of each individual's reading rate from

Table XII. Summary of Analysis of Variance:
Factorial Counting Method

his average reading rate for each of the four intervals. Thus, all individual scores have a common basis of comparison with less variation between the scores. The average reading rate for the group is also given as the average deviation of the rates for the four subjects at each of the four reading periods. The curves obtained for each individual and the group averages are shown in Figures 2-28. The dotted lines on these curves represent each individual's deviation from his own overall mean reading rate at successive twenty-five minute reading periods. Thus, zero on the ordinate represents each subject's overall mean reading rate. The solid lines indicate the group averages.

There is considerable variability within subjects and between subjects for any particular spacing combination. The curve for the mean reading performance for each combination reflects this variability. The trends can be seen more clearly if the spacing variables are plotted independently. Thus, the performance on successive twenty-five minute reading periods for all subjects who read combinations which included the .080" dot spacing are plotted regardless of the values of the other variables. This was done for each of the nine values, three for each spacing variable. The average number of words per minute obtained at successive twenty-five minute periods for each of the values of spacing between dots, cells, and lines is shown in Figures 29, 30, and 31 respectively. The points on the curves are made up of nine group means consisting of four subjects, or a total of thirty-six subjects. In general,

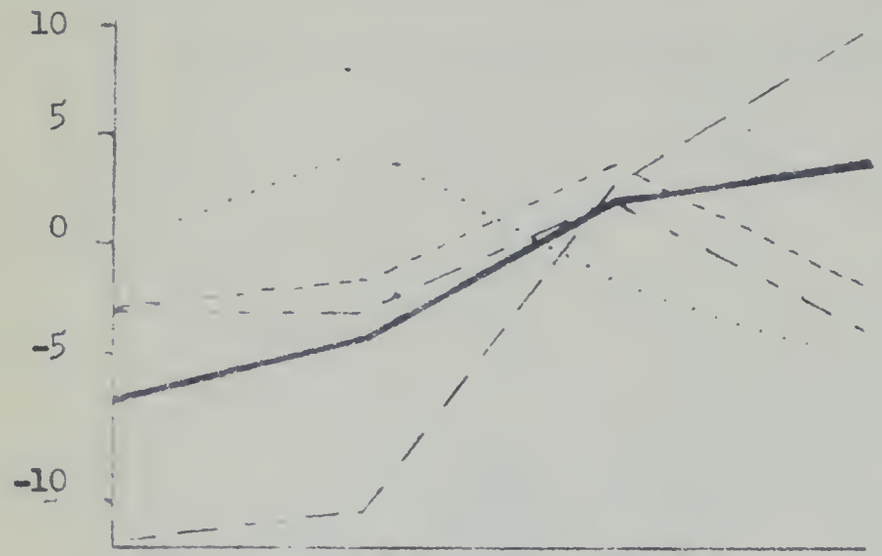

Fig. 2. .090" - .140" - .300"

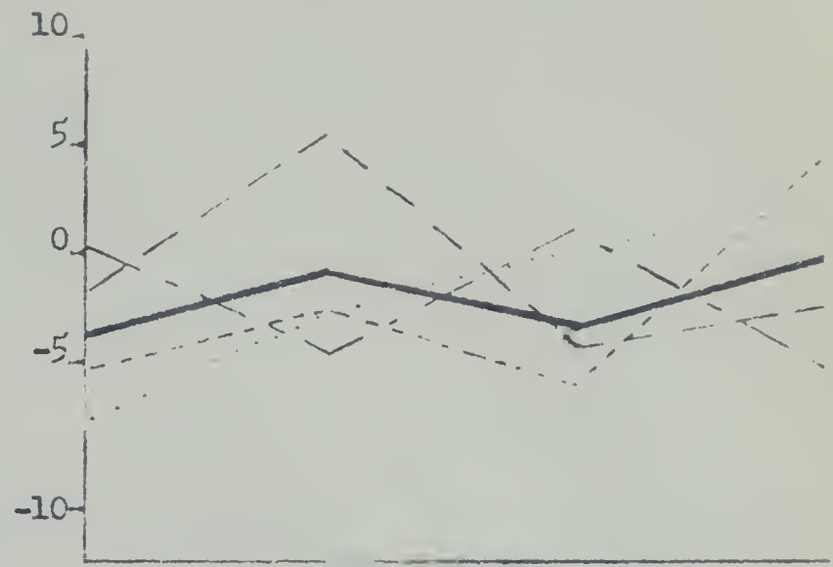

Fig. 3. .080" - .160" - .300"

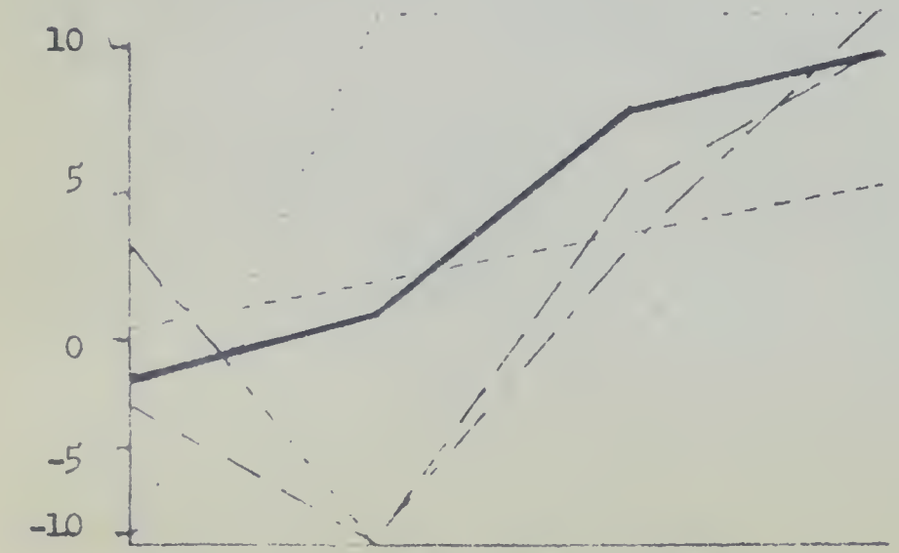

Fig. 4. .100" - .123" - .163"

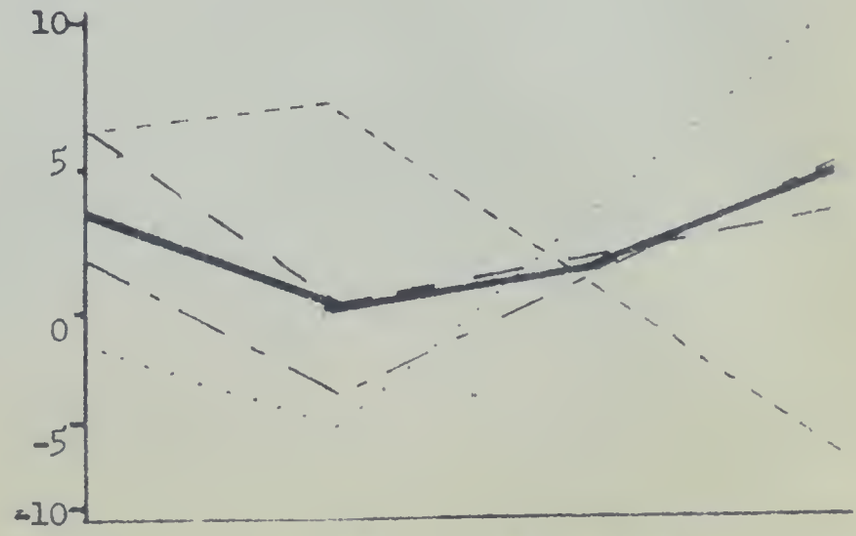

Fig. 5. .100" - .160" - .300"

See preceding page for explanation of Figs. 2 - 28.

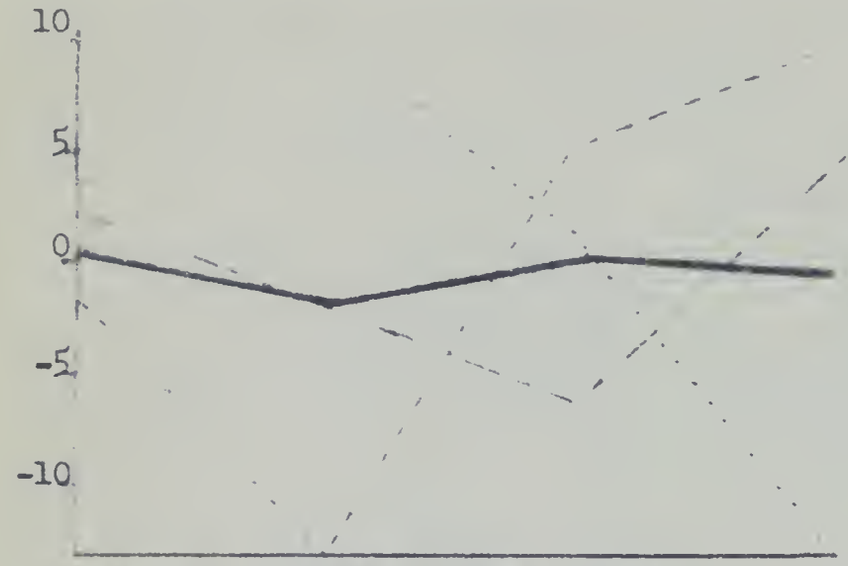

Fig. 6. .080" - .140" - .163"

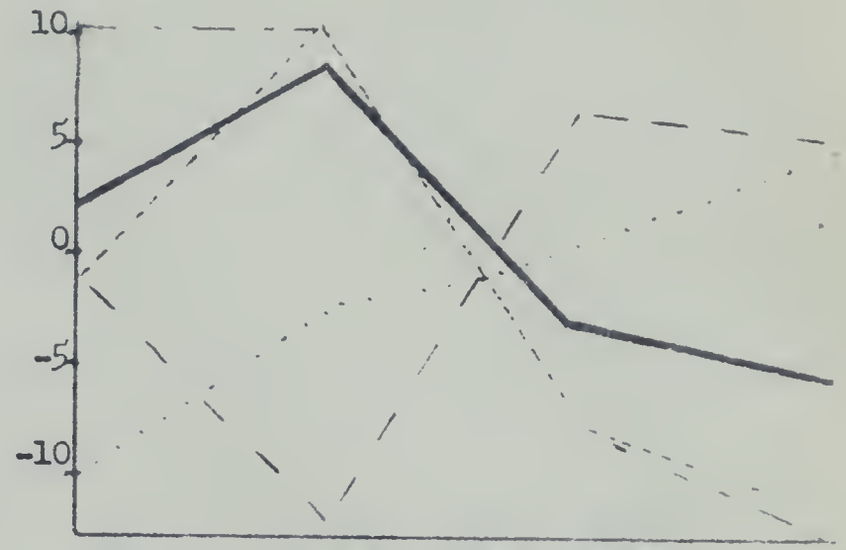

Fig. 7. .080" - .123" - .220"

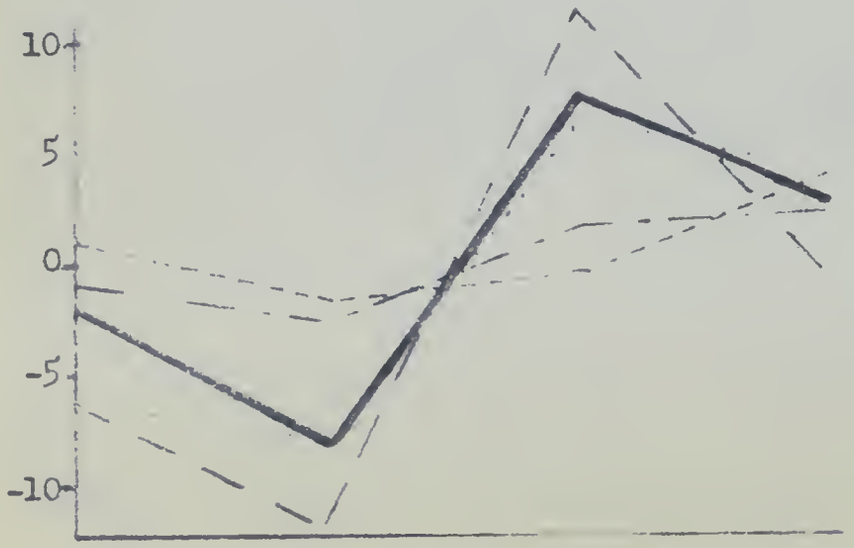

Fig. 8. .080" - .140" - .220"

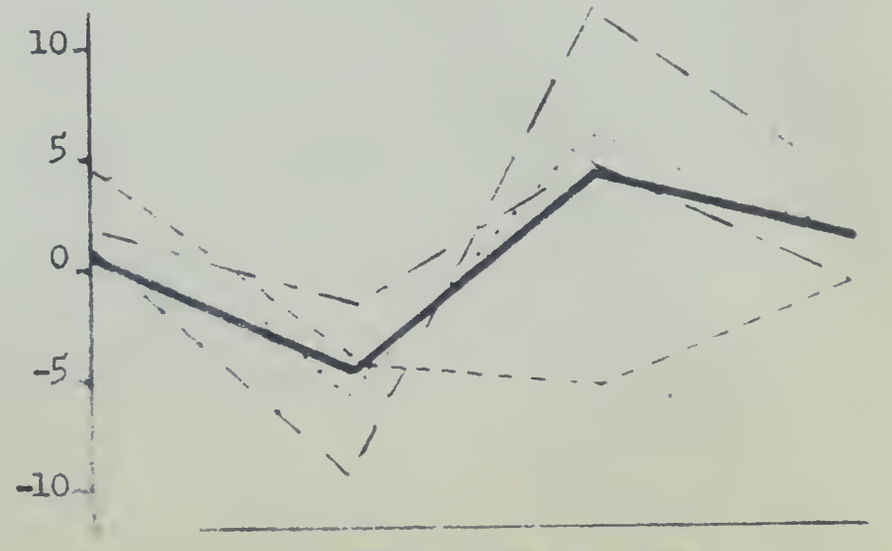

Fig. 9. .090" - .160" - .220"

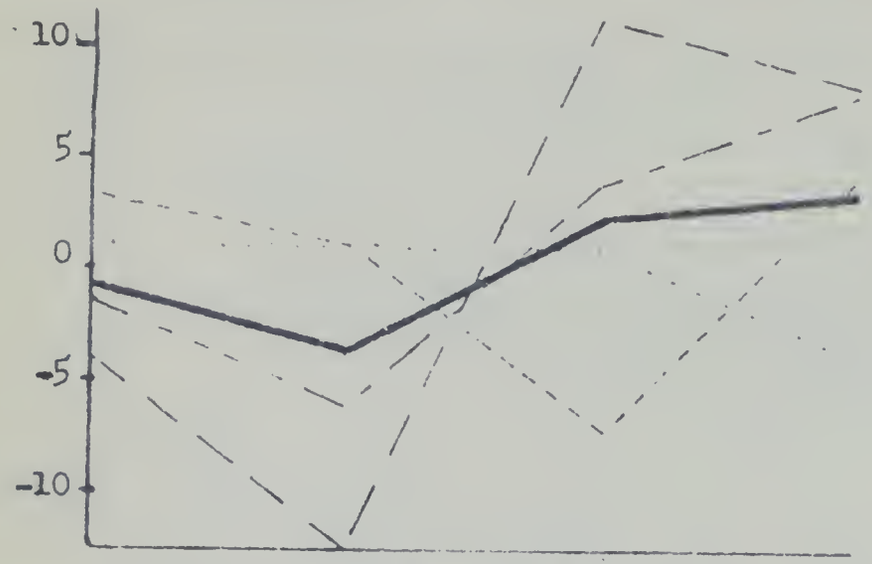

Fig. 10. .080" - .123" - .300"

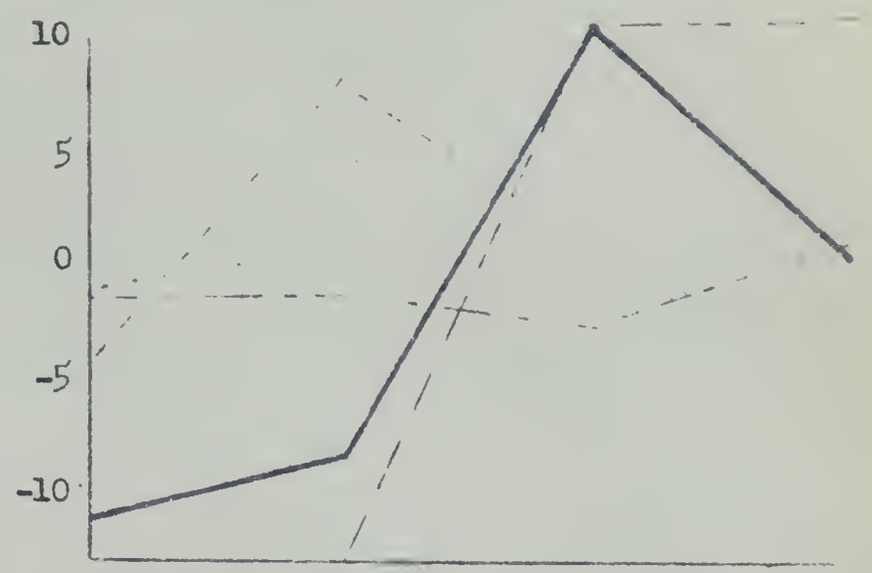

Fig. 11. .100" - .123" - .220"

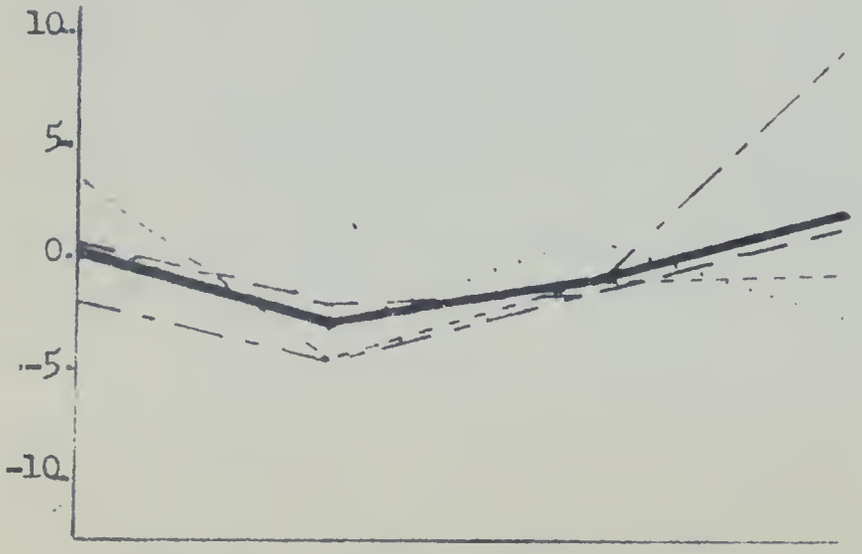

Fig. 12. .090" - .160" - .163"

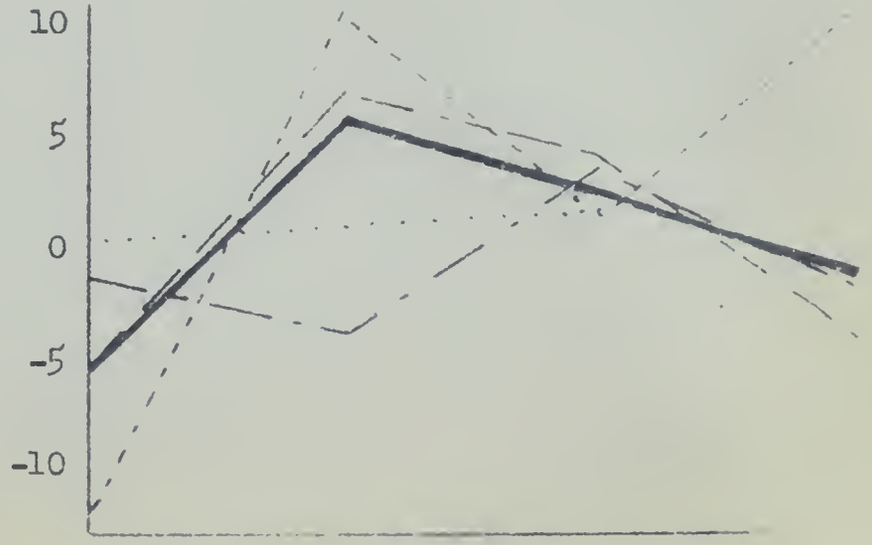

Fig. 13. .090" - .140" - .220"

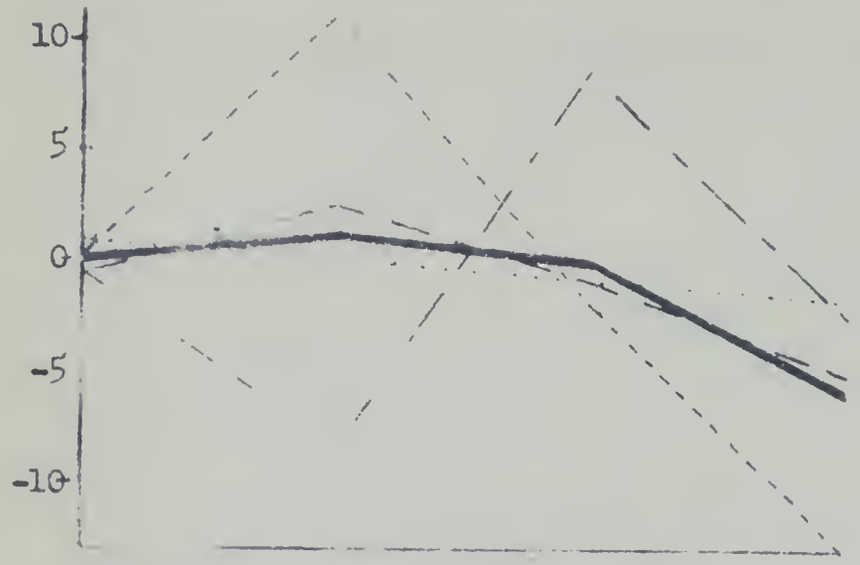

Fig. 14. .080" - .123" - .163"

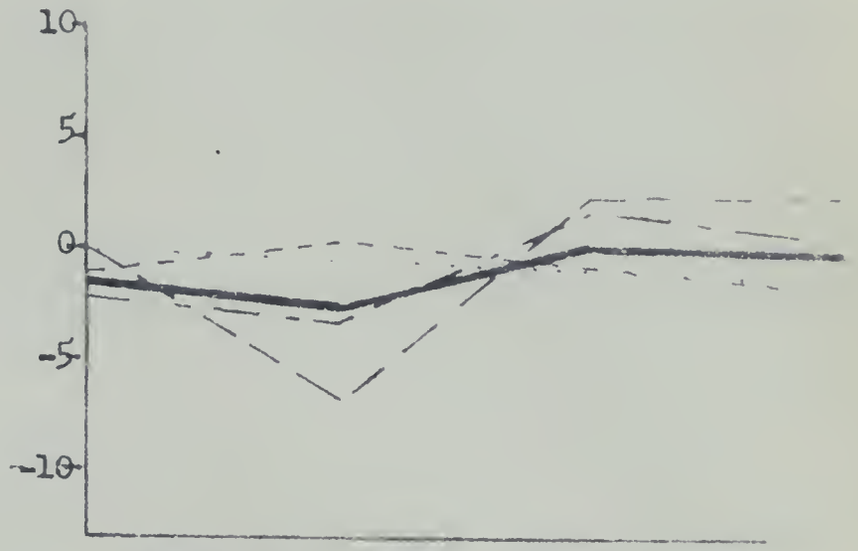

Fig. 15. .080" - .140" - .300"

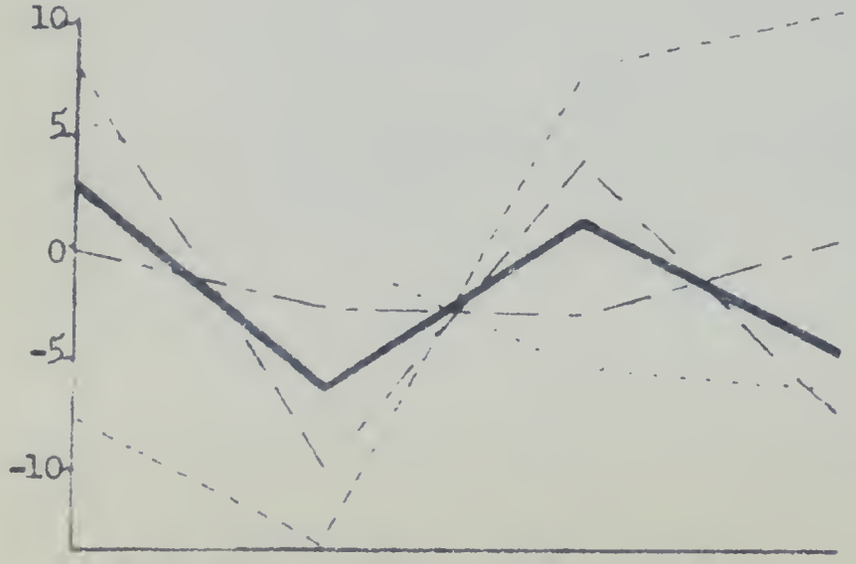

Fig. 16. .090" - .140" - .163"

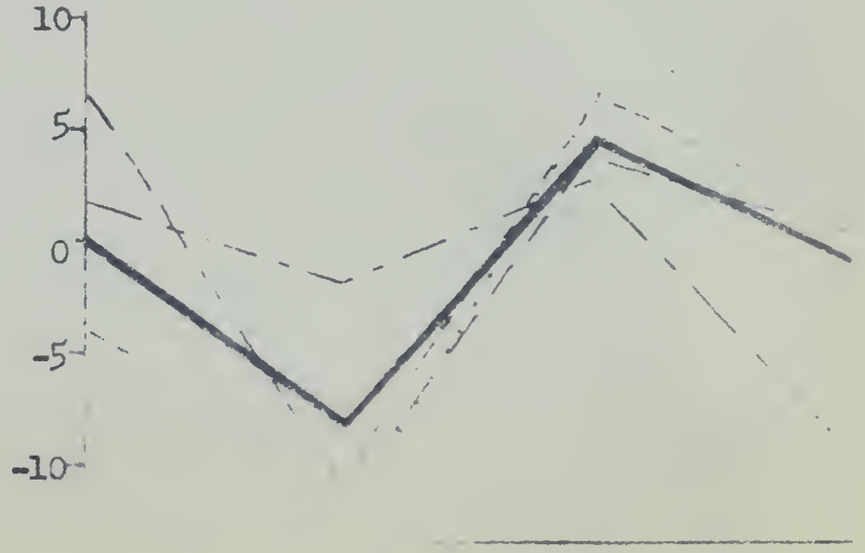

Fig. 17. .090" - .123" - .300"

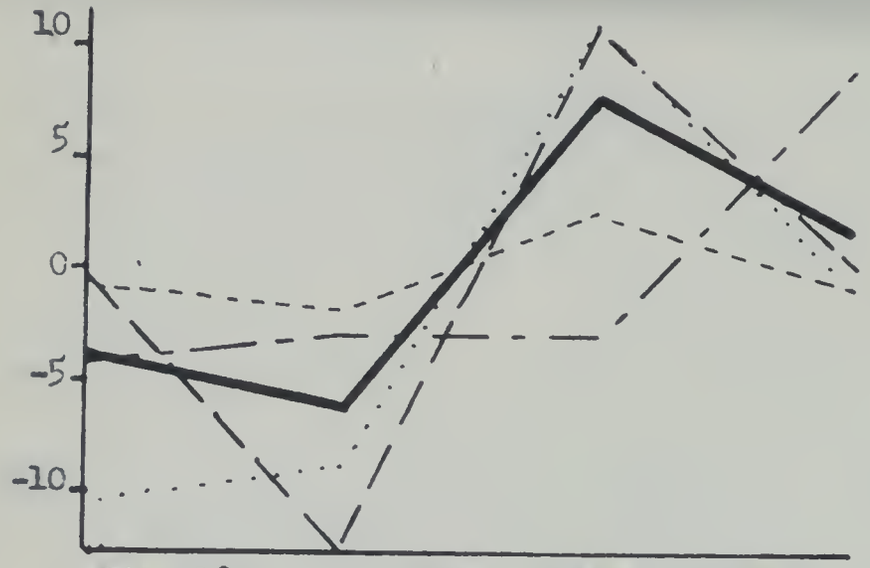

Fig. 18. .100" - .160" - .220"

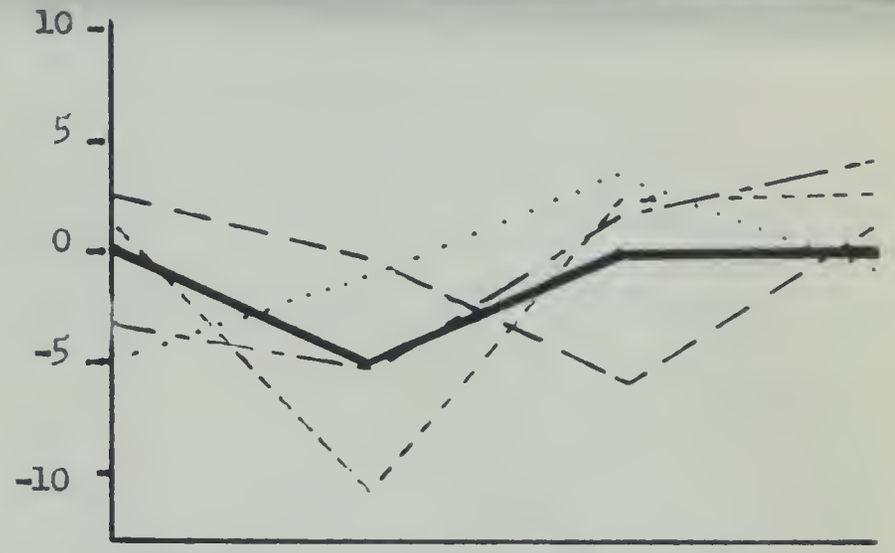

Fig. 19. .100" - .140" - .163"

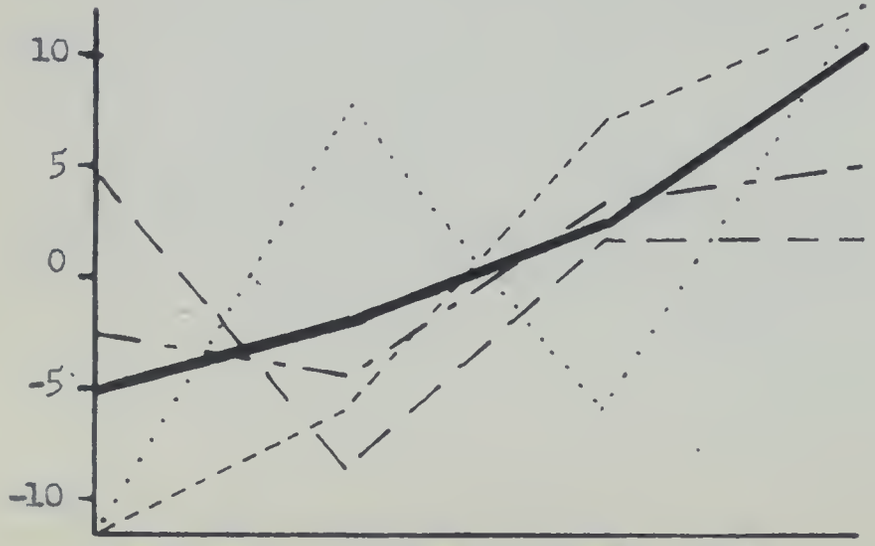

Fig. 20. .100" - .160" - .163"

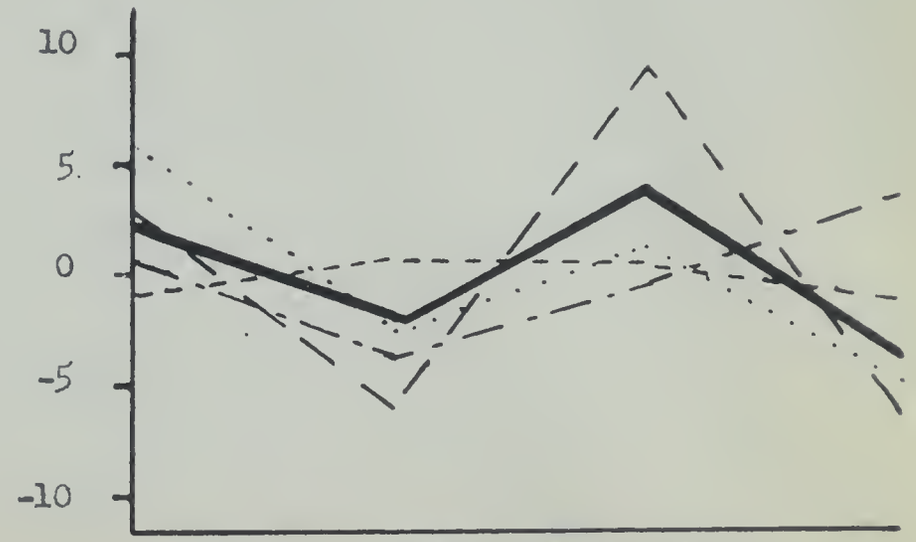

Fig. 21. .090" - .123" - .163"

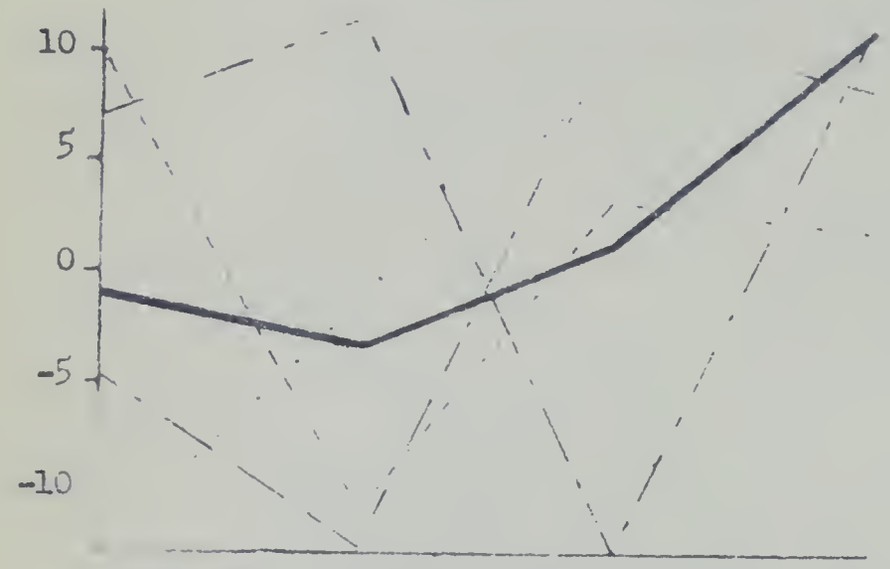

Fig. 22. .100" - .123" - .300"

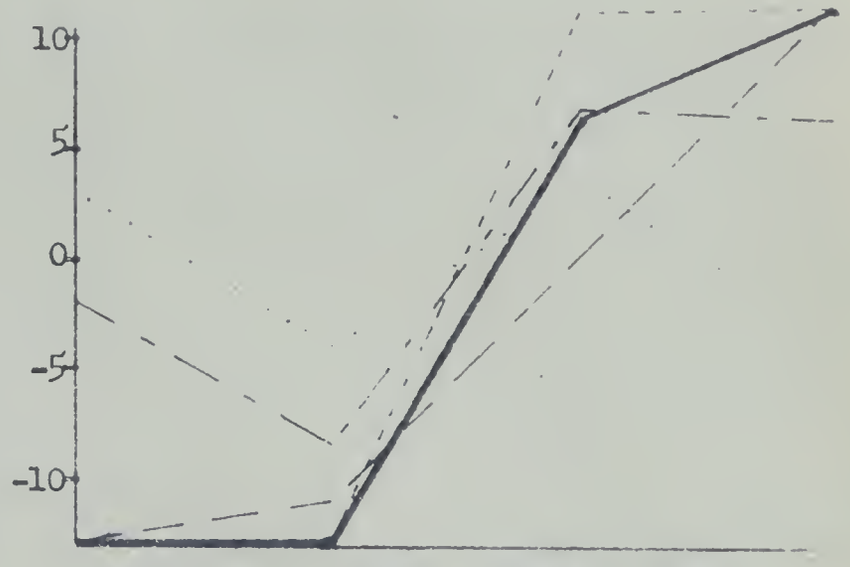

Fig. 23. .090" - .160" - .300"

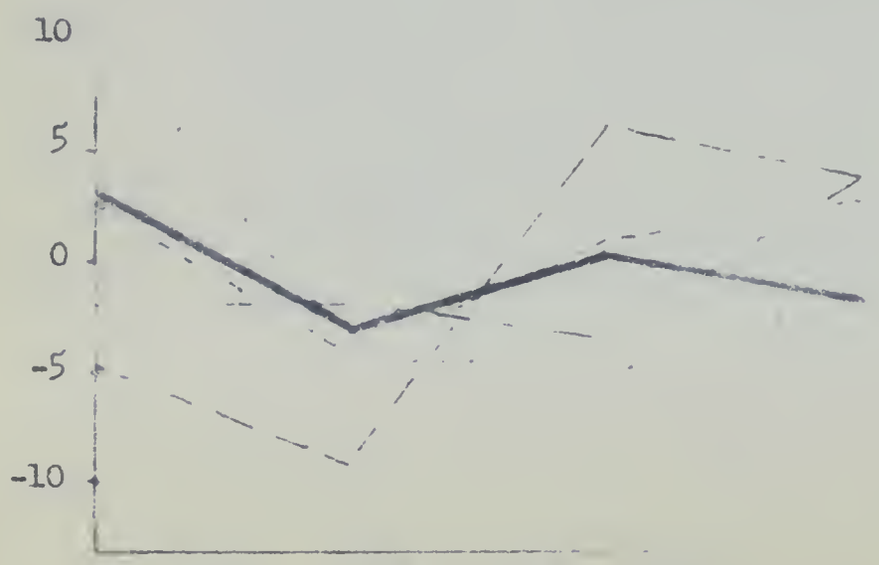

Fig. 24. .080" - .160" - .220"

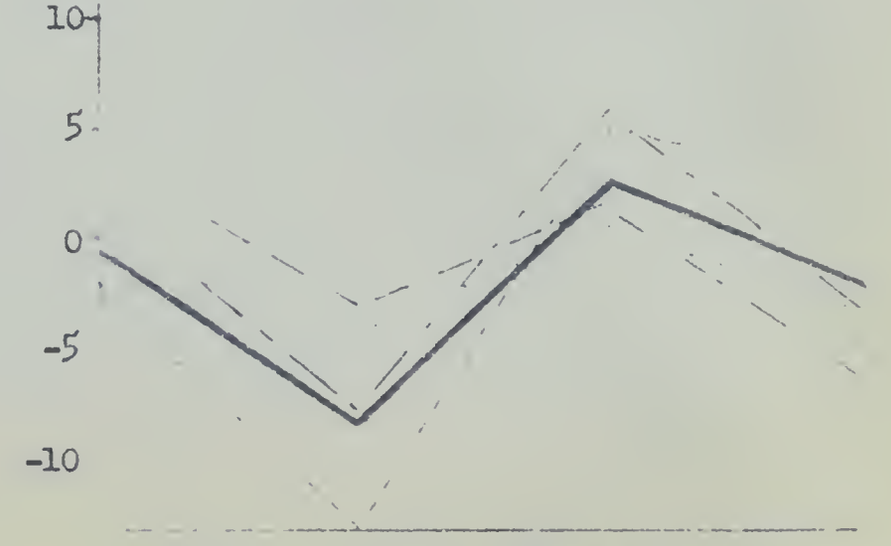

Fig. 25. .100" - .140" - .300"

Figure 26. .080" - .160" - .163"

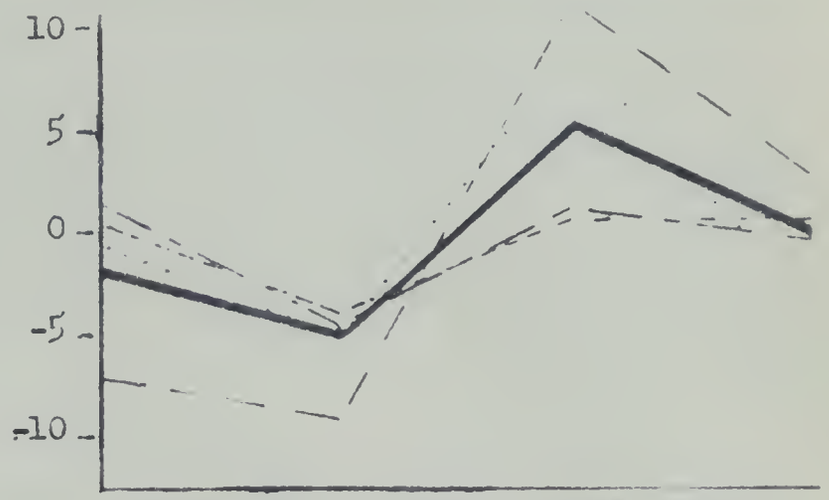

Figure 27. .100" - .140" - .220

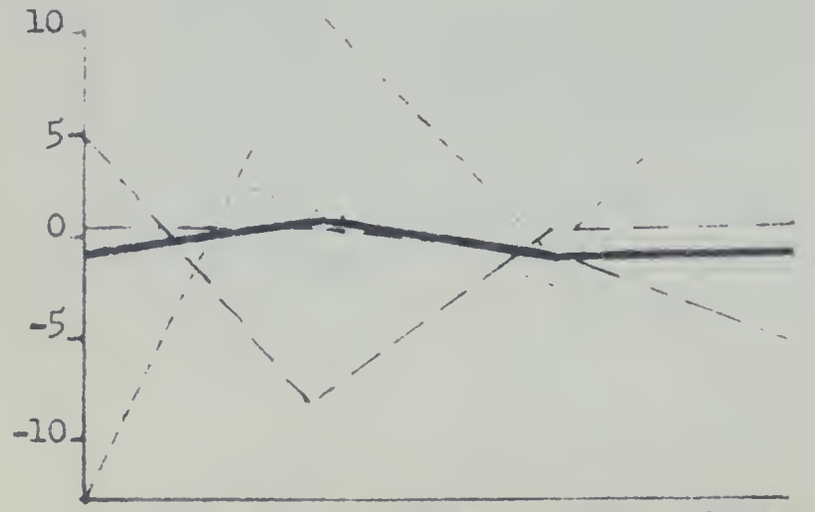

Figure 28. .090" - .123" - .220"

the curves seem to rise with continued practice with the material, showing a slight decrease in reading rate during the second twenty-five minutes of each reading period. Differences between the spacing values are more obvious when the data are plotted in group means, removing the emphasis on individual variability. Tests for trend [37] were made on each of the spacing variables.

Test for Trend--Between Dot Spacings. Material printed with each of the three values of spacing between dots was read by thirty-six subjects. The average number of words per minute read for each of these values at the different reading periods is shown in Figure 29.

The curve for the smallest spacing between dots (.080") falls below the curves for the other two values throughout the reading periods. The subjects reading with the largest spacing between dots (.100") initially fall below those reading the standard spacing value, but exceed them five words per minute on the second day.

A test for trend was made on these three values of dot spacing for the four reading periods. The F obtained between the slopes of the curves for the three spacing values is significant at the .001 level. The curves in Figure 29 suggest that this difference is between the spacing value of .080" and either of the other two values.

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37. H. W. Alexander, "A General Test for Trend", Psychological Bulletin, 1946, P. 533-557.

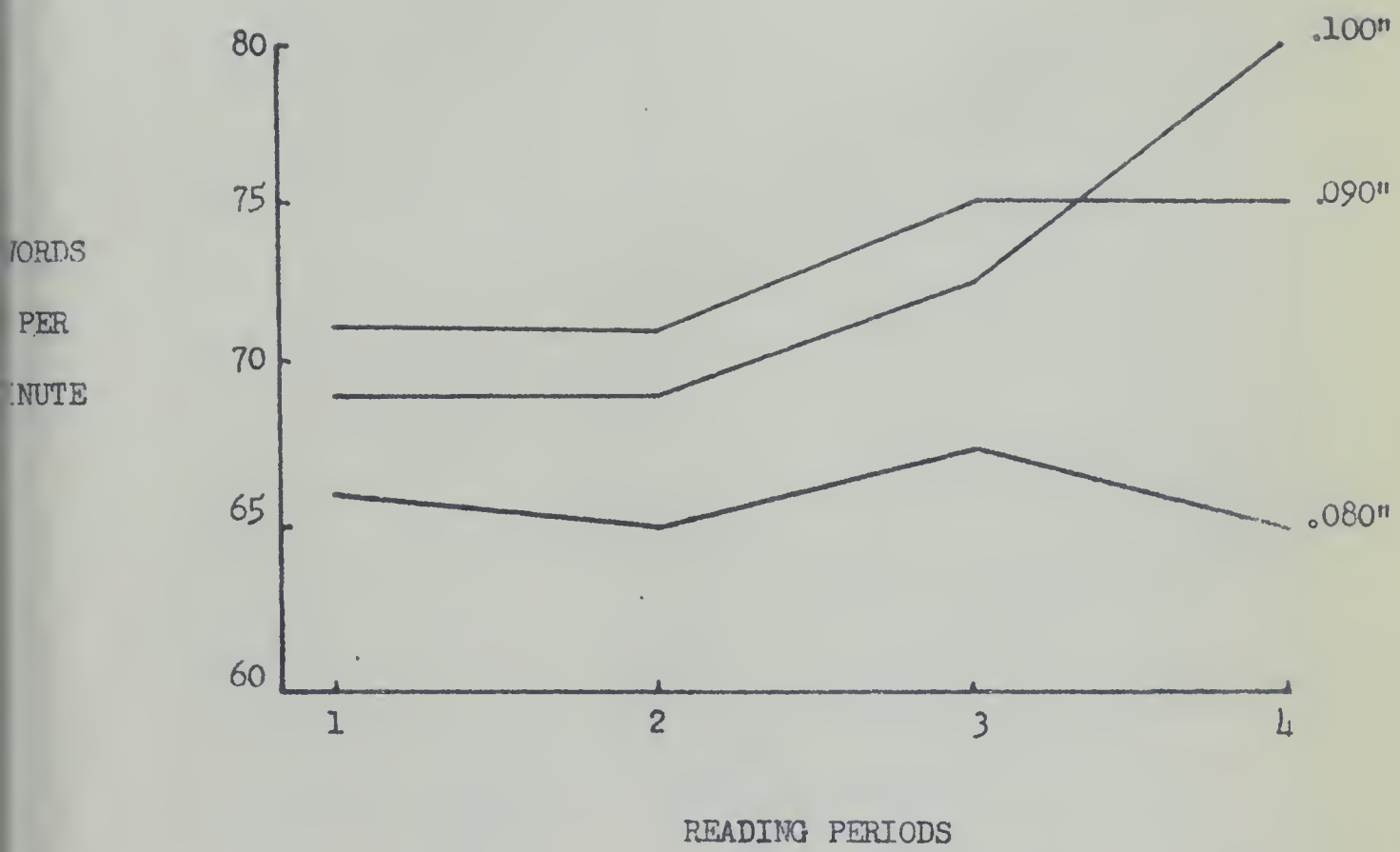

Figure 29. Average number of words per minute at successive reading periods with three values of spacing between dots.

The Alexander trend analysis provides several kinds of comparisons. For our purposes the two most important comparisons are of the overall slopes of the curves and comparisons of the levels of the curves. The former tells us whether the curves tend to have the same curvature or direction and the latter tells us whether or not the reading rates are different for the different values. The difference in levels is often referred to in the discussion as the difference in group means. The previous analysis provided a different and less sensitive method of analyzing differences in group means.

The sources of variation in the analysis and the obtained F. values are given in Table VIII. The error term used in the analysis was "individual deviations from estimation". As "group deviations from estimation is not significantly greater than error, there is no systematic deviation from linearity in the sub-groups. However, there is a significant trend in the "overall deviation." The F obtained "between individual slopes" (Figs, 2-28) is greater than is to be expected by chance, indicating that the slopes between the individuals within a group are significantly different. The F obtained for "between group means" for reading rate is significant at the .001 level. The different levels of the curves in Figure 29 would again indicate a difference between the smallest spacing (.080") and the other two values.

Source	df	SS	MS	F
Individual Deviations from Estimation	48	6653	138.60	
Group Deviations from Estimation	4	76	19.00	
Overall Deviations from Linearity	2	1830	915.00	6.6
Between Individual Slopes	24	13121	546.71	3.9
Between Group Slopes	2	5798	3899.00	20.9
Overall Slope	1	7384	7384.00	53.2
Between Individual Means	24	103585	4316.04	31.1
Between Group Means	2	20336	10168.00	73.4

Table VIII. Summary of Test for Trend -- Between Dot Spacings.

Analysis of Variance -- Between Dot Spacings. Two factor analyses of Variance were made between .080" spacing between dots and each of the larger values. These analyses were made of the difference between the means at the successive reading periods. A distance of .080" between the dots was found to be read at a significantly lower rate than either of the larger spacings. The summary of the analysis between .080" and .090" is given below in Table IX. The obtained F = 10.40 is significant at the .005 level.

Source	df	SS	MS	F
Values	1	16775	16775.00	10.40**
Intervals	3	2273	757.66	
Values X Intervals	3	1447	482.33	
(Cells)	(7)	(20495)		
Within Cells	64	103276	1613.69	
Total	71	123771	**p =	.005

Table IX. Analysis of Variance Between .080" and .090" Distance Between Dots.

The two factor analysis of variance between .080" and .100" dot gave a F of 18.48 which is significant at the .001 level. The summary for this analysis is given in Table, X.

Source	df	SS	MS	F
Values	1	13558	13558.00	18.48**
Intervals	3	5958	1986.00	
Values X Intervals	3	5820	1940.00	
(Cells)	(7)	(25336)		
Within Cells	64	46960	773.75	

Table X. Analysis of Variance Between .080" and .100" Distance Between Dots.

The variance due to the twenty-five minute reading intervals, or due to the interaction of the different values at the four intervals, was found to be no greater than chance in each of the analyses. From this it appears that the differences between the slopes of the curves that were found to be significant in the test for trend are apparently between the combination of the three curves and not between .080" and either of the other values as is suggested by inspection of the curves alone.

Test for Trend -- Between Cell Spacings. The average number of words per minute read by each of the groups reading material with the different spacing values for Braille cells is shown in Figure 30.

The smallest value of spacing between cells (.123") maintained the highest reading rate for all the reading periods. The standard spacing value. (.160"), which is the largest value in the study, was read at the lowest rate for the first three

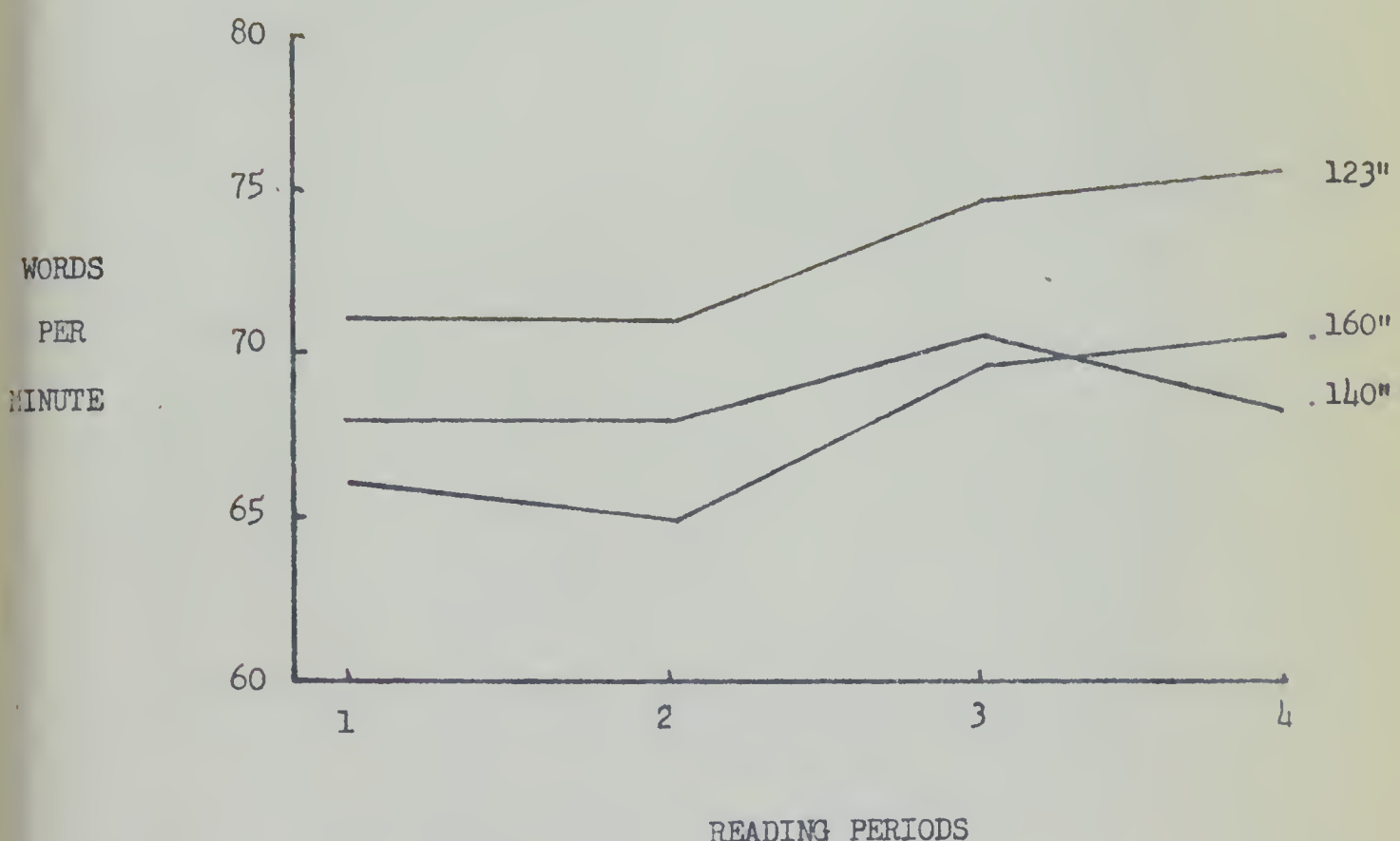

Figure 30. Average number of words per minute at successive reading periods with three values of spacing between cells.

reading periods, but slightly exceeded the middle value during the fourth reading period.

Alexander's test for trend was also made for the different values of cell spacing. A summary of the analysis is given in Table XI.

Source	df	SS	MS	F
Individual Deviations from Estimation	48	6296	131.16	
Group Deviations from Estimations	4	453	108.25	
Overall Deviations from Linearity	2	1830	915.00	6.97**
Between Individual Slopes	24	18105	754.37	5.8 *
Between Group Slopes	3	814	407.00	3.1 *
Overall Slope	1	7384	7384.00	56.3 *
Between Individual Means	24	116631	4859.62	37.1 *
Between Group Means	2	7290	3645.00	27.8 *

*p = .001 **p = .005

Table XI. Summary of Test for Trend--Between Cell Spacings.

The error term used in the analysis was "individual deviations from estimation." The obtained F = 3.1 between the slopes of the curves exceeds chance differences.

The slopes of the curves in Fig 30 appear to be remarkably alike except for the drop in the last reading period for those who read Braille which had a cell spacing of .140". This apparantly accounts for the significant difference in slopes. "Between Group Means" obtained a significant F in the analysis, indicating a difference between the levels of the curves. In this instance, it is not so obvious from an inspection of the curves in Figure 30 just where this difference is to be found.

Analysis of Variance--Between Cell Spacings.

Separate two factor analysis of variance were made of .123" distance between cells and each of the larger values of between cells spacing. The summary of the analysis between .123" and .140" spacings is presented in Table XII. The obtained F of 2.76 shows only chance differences between the values.

Source	df	SS	MS	F
Values	1	3960	3960.00	2.76
Intervals	3	4519	1506.33	1.05
Values X Intervals	3	519	173.00	
(Cells)	(7)	(8998)		
Within Cells	64	91838	1434.97	
Total	71	100836		

Table XII. Analysis of Variance Between .123" and .140" Distance Between Cells.

The F = 4.10 obtained between the values of .123" and .160" indicates beyond chance differences at the .05 level. The summary of this analysis is given in Table XIII.

Source	df	SS	MS	F
Values	1	6763	6763.00	4.10
Intervals	3	7827	2609.00	1.58
Values X Intervals	3	202		
(Cells)	(7)	(14792)		
Within Cells	64	105474	1648.03	
Total	71	120266		

Table XIII. Analysis of Variance Between .123" and .160" Distance Between Cells.

Apparently the significant difference that was obtained between the means in the test for trend is a difference between the smallest spacing and the larger spacing between cells.

Test for Trend--Between Line Spacings. The average number of words per minute at the four successive time intervals for the three values of line spacing is shown in Figure 31.

A spacing between lines of .220" maintains a high reading rate throughout the four reading periods. The two extreme values of .300" and .163" are read approximately seven words per minute less than the middle value of line spacing. The curve for the larger line spacing (.300") does rise during the second day, suggesting the possibility that reading rate increases with greater familiarity.

Alexander's test for trend was also made for the three values of spacing between lines. The summary for this analysis is given in Table XIV.

Source	df	SS	MS	F
Individual Deviations from Estimation	48	6354	132.37	
Group Deviations from Estimation	4	375	93.75	
Overall Deviations from Linearity	2	1830	915.00	6.9**
Between Individual Slopes	24	17706	737.75	5.6*
Between Group Slopes	2	1213	606.50	4.6***
Overall Slopes	1	7384	7384.00	55.8*
Between Individual Means	24	3417	142.37	1.1
Between Group Means	2	20504	10252.00	77.5*

*p = .001, **p = .005, ***p = .05

Table XIV. Summary of Test for Trend--Between Line Spacings.

With "individual deviations from estimation" again employed as the error term in the analysis, the F indicated greater than chance differences in slope.. Thus, there is a difference between the slopes of the three values of line spacing. The difference obtained "between group means" is greater than is to be expected by chance. The difference between the levels of the curves is apparently between the standard value of distance between lines and either of the other two values.

Analysis of Variance--Between Line Spacings.

When a two factor analysis of variance was made between ,220" and the smallest spacing between lines (.163") at the successive reading periods, a F value greater than is expected by chance is obtained. The analysis between .220" and .300" spacings between lines also revealed significant differences. Thus, the difference between the curves for .220" and .300" in Figure 31 is

greater than is to be expected by chance. A summary of the analysis between .220" and .163" spacings between Braille lines is given in Table XV. The obtained F = 14.31 is significant at the .001 level.

Source	df	SS	MS	F
Values	1	17360	17360	14.31*
Intervals	3	3639	1213	1.0
Values X Intervals	3	342	114	
(Cells)	(7)	(21341)		
Within Cells	64	77643	1213	
Total	71	98984	*p = .001	

Table XV. Analysis of Variance Between .220" and .163" Distance Between Lines

Table XVI gives a summary of the analysis made of .220" and .300" values, with the F = 7.35 being significant at the .01 level.

Source	df	SS	MS	F
Values	1	13095	13095.00	7.35*
Intervals	3	8924	2974.66	1.67
Values X Intervals	3	736	245.30	
(Cells)	(7)	(22755)		
Within Cells	64	113927	1780.10	
Total	71	136682	*p = .01	

Table XVI. Analysis of Variance Between .200" and .300" Distance Between Lines

Apparently a distance of .220" between Braille lines permits greater readability than a spacing of .163" or .300".

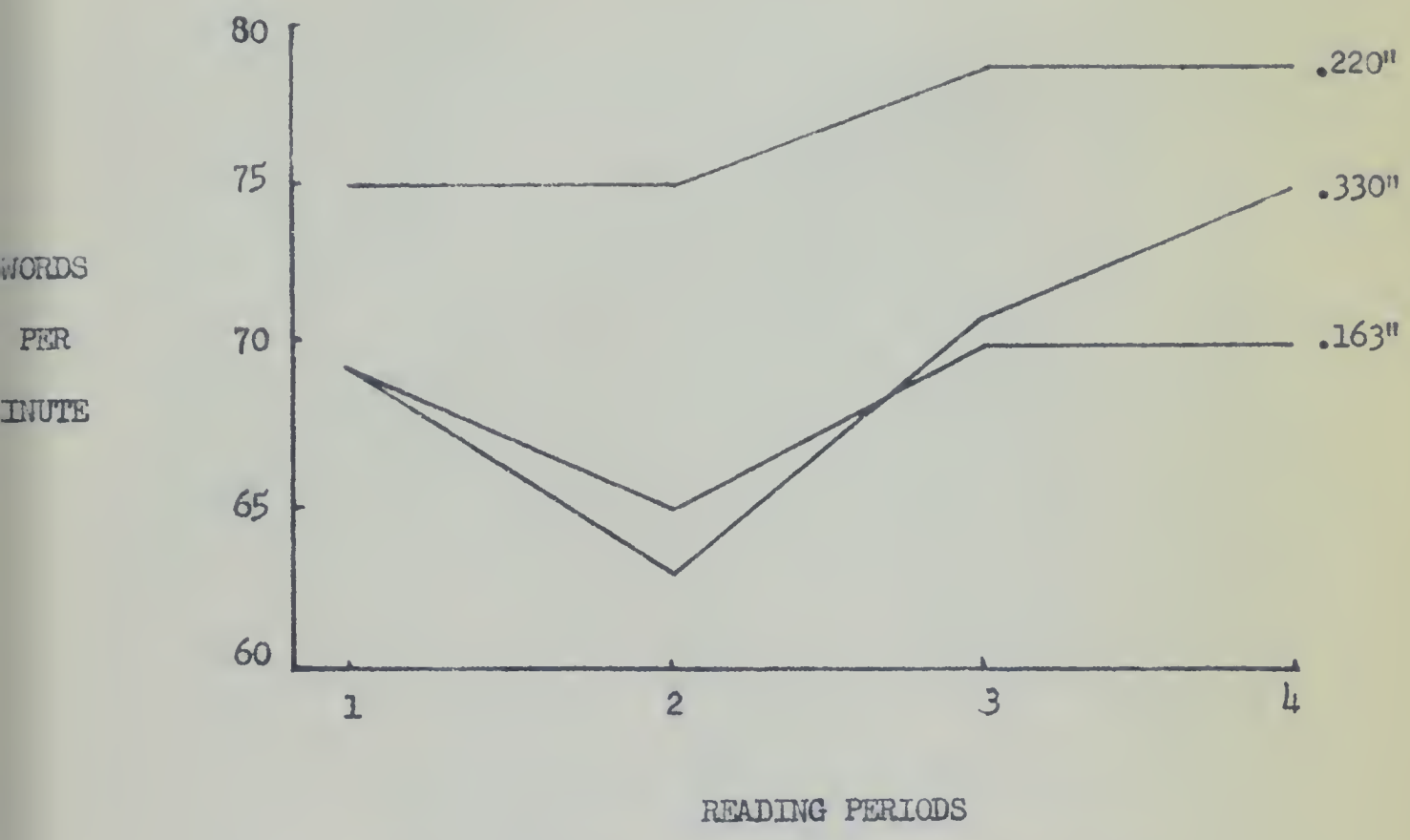

Figure 31. Average number of words per minute at successive reading periods with three values of spacing between lines.

SUMMARY OF RESULTS OF FIRST INVESTIGATION

An analysis of variance showed that the differences between the means of the twenty-seven combinations and of the means of the nine values of spacing variables were attributable to chance.

This analysis was also made upon the scores for the first fifty-minute reading period and the second fifty-minute period to determine initial or final differences between the combinations. There were only chance differences between the means at each of the reading periods.

The words per minute were computed at successive twenty-five minute periods for each of the twenty-seven combinations to detect any differences in trend for the nine different values. Alexander's test for trend was made separately on the three values of each of the spacing variables. There were differences in slope between the three values of dot spacing, the three values of line spacing, and the three values of cell spacing. These differences are apparently attributable to the smaller dot spacing, and the middle values of cell spacing and line spacing. The reading rate for the smallest dot spacing value (.080") slightly decreases during successive periods, where as the reading rates for the larger values (.090" and .100") increase with continued practice.

The curves for the three values of line spacing at the different intervals suggest a difference in slope between the middle value of line spacing (.220") and each of the other two values. The subjects reading material with the

extreme values of line spacing showed a slight decrease in reading rate during the first period and a slight increase during the second period, whereas the subjects' reading material with .220" spacing did not change in reading rate during either period. All values showed an increase in reading speed on the second day.

In each of the tests for trend for the three spacing variables, the differences between the group means were found to be significant at the .001" level.

The factor analyses of variance were made to determine which of the values within each of the three spacing variables were significantly different. Significant differences were found between .080" and each of the other two values of dot spacing, and between .220" and each of the extreme distances between lines. There was also a greater than chance difference between a cell spacing of .123" and .160". No significant difference was found between .123" and .140" spacings.

INTERPRETATIONS AND CONCLUSIONS OF FIRST INVESTIGATION

Even though the overall analysis of variance showed that the particular combinations used in the experiment were similar in their effect, specific values within each of the spacing variables were found to be read at a higher rate. The tests for trend indicated that there were significant differences between values for each of the spacing variables. That extra-chance differences were found for each of the variables in the three tests is sufficient evidence to support the conclusion that some of the values permit greater readability. However, the conflicting results for the two types of analyses remain to be explained.

The error term employed in the analysis of variance to test the significance of the mean squares obtained by each of the spacing variables was "within groups" mean square. That is the amount of variance contributed by the differences between the four individuals reading any specific combination. It is to be remembered that the four individuals within any one group were selected from different quartiles of the distribution for reading rates. Therefore, this error term was large and the differences between the values of any specific spacing variable would have had to be very large to have reached a significant level.

The tests for trend employed the differences in reading rates for the values at successive twenty-five

minute reading periods. The error term used was "individual deviations from estimation", which, in this analysis, is the variation between individuals within a group around the values which would have been obtained if there were only chance differences. These analyses employ the total number of words read by the twenty-seven different groups at successive intervals. The error term, then, consisted of group variations at successive intervals instead of individual variations within a group, which is smaller than the error term employed in the analysis of variance. Thus, the test for trend would be more sensitive to smaller differences between the spacing variables.

The error term employed for the two factor analyses of variance was also the variation of the groups at successive reading intervals. Therefore, significance would be attributed to smaller differences than in the three factor analyses.

The following conclusions are made on the basis of the results obtained employing the smaller error term, that is, differences between the groups reading material with one specific value of each of the spacing variables. The three variables, spacing between dots within Braille cells, spacing between cells, and spacing between lines will be discussed separately.

Of the three values of spacing between dots .080", .090", and .100", employed in the investigation, the smallest distance (.080") is obviously least readable.

It is more difficult to distinguish between the effects of the two larger values. In spite of the fact that there is only a slight difference in the mean reading rates obtained for these values, there is dissimilarity in the rates at successive reading periods. Initially the standard value, .090", is read at a higher rate. However, in the final stages of the reading period, .100" distance between dots is superior. No definite decision concerning these two values can be made without additional research. It seems that a spacing of .100" between dots may be the most desirable, if the blind readers were accustomed to this spacing. However, the safest conclusion to be made at this time is that a dot spacing of .090" or .100" permits greater readability than the smaller value, .080".

Differences greater than chance were obtained in the overall analysis of the data for the three cell spacing values.

From the graph (Figure 30) it appears that the smallest distance between Braille cells (.123") is more readable than .140" or .160". However, the difference between .123" and .140" is not large enough for significance. The difference between .123" and .160" distance between Braille cells is statistically significant.

The present specification of distance between Braille lines (.220") was read at a significantly greater rate than either of the two extreme values employed in the experiment (.163" and .300"). During the final reading period there was an increase in rate for the subjects reading material

with .300" spacing between lines. This could be only random fluctuation, or it might be suggestive of increased readability with further practice with this larger distance between lines. However, this cannot be determined on the basis of the data from this investigation alone.

From this, it seems that the standard distances or a larger distance between dots, a smaller distance between cells, and the standard distance between lines for Braille print would achieve the highest reading rate.

Evan though these values separately obtained higher reading rates, it is very possible that the combinations of the three values might be less readable. The four subjects reading material with the combination of .100"-.123"-.220" gained a total of thirty-four words per minute as compared to their reading rate with standard values of spacing. The four subjects reading with the combination of .090"-.133"-.300" gained sixty-four words per minute over their reading rate with standard Braille specifications. However, no conclusion as to the readability of these combined values could be made only on the basis of so few subjects.

It must also be remembered that this experiment has employed three specific values of each of the spacing variables. It is very possible that a value between the selected dimensions might be most desirable. Further research on values between .090" and .100" spacing between dots, employing a longer reading period seems necessary to distinguish between the two.

Burklen[38] suggested that the most desirable spacing for dots was a value between 2 and 3 mm. From the results of the present experiment, the lower limit, 2mm., or .079", would apparently need to be raised as .080" was less readable than the larger values.

It is also possible that a distance smaller than .123" between Braille cells, and a value slightly larger or smaller than .220" between lines would permit faster reading by blind readers.

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38. Karl Burklen, Touch Reading of the Blind, 1932, P. 52

SUMMARY OF THE FIRST INVESTIGATION

Three values of spacing between dots within Braille cells, .080", .090", .100", three values of spacing between cells, .123", .140", .160", and three values of spacing between Braille lines, .163", .220", .300", were read in all possible combinations to determine the most desirable specifications for Braille print. A total of 108 blind subjects was employed, each combination of values was read by four subjects and any one value was read by thirty-six subjects.

Reading rates were computed for all subjects reading for thirty-minutes with standard Braille specifications from a novel readable at fifth grade level. Material from the same novel was printed in the twenty-seven different combinations of values and was read by groups with similar reading rates.

An analysis of variance was made of the total number of words read by the groups in two fifty-minute periods, and of the number of words read for each of the fifty-minute periods separately. These analyses indicated that the particular combinations were similar in effect.

Tests for trend were made between the values of each of the three spacing variables separately, indicating difference between the means of the values for each of the variables.

Two factor analyses of variance were made of the reading rates at four successive reading intervals with two values of each of the spacing variables. Differences were found between .080" and each of the other two values of dot spacing, between .123" and .160" spacing between cells, and between .220" and each of the extreme distances between lines.

A spacing combination of .100" or .090" between dots within a Braille cell, .123, or .140" between cells, and .220" between lines is suggested as the most desirable specification for Braille print.

PROCEDURE FOR THE SECOND INVESTIGATION

A similar investigation was done with adults. The subjects were volunteers from New York City; Louisville, Kentucky; Indianapolis, Indiana; Nashville, Tennessee; Jacksonville, Illinois; Columbus, Ohio; and St. Louis, Missouri.

They read the same material as the children. This was true for both the equating and experimental Braille. The instructions were essentially the same in both instances; and the questions asked the subjects at the end of the equating and experimental readings were identical. Also, the criteria for the number of the comprehension questions answered correctly in order for subjects to be included in the study remained the same.

One hundred and sixty-seven adults read equating material. Their average reading speed was 91.69 words per minute (Appendix VI). This is considerably faster than the reading speed of the children (68.0 words per minute). However, a disproportionate number of adult readers were teachers in schools for the blind. A more representative sample of adult blind readers may average less than 91.69 words per minute. Nevertheless a wide range of reading speed is included in the sample of subjects who read the equating material. The words per minute range from 3.0 to 199.0. (Appendix VI).

As in the previous investigation the equating scores were arranged in quartiles and for each of the twenty-seven combinations, four readers were selected, one from

each quartile. However, because of the fewer number of available subjects it was impossible to exactly equate each group of four reader for their reading speed. Instead readers from each quartile were selected from a table of random numbers. However, all of the twenty-six subjects from New York City were used for the experimental study, since the equating and experimental readings were accomplished in one visit to that city. Also, many of the subjects from other cities who were originally selected randomly were not available for the experimental reading and substitute subjects had to be selected from the pool of subjects who read the equating material. With the exception of New York, each city was visited at least twice after the equation chapters were read, in an attempt to contact subjects.

There were three readers instead of four, for two of the twenty-seven combination, (.080"-.123"-.200" and .100"-.123"-.163") This is explained by the fact that due to irregularities the work of two of the subjects could not be included in the results. Appendix (VII) shows the reading speeds of subjects for the experimental combinations.

The authors hold that both investigations (children and adults) were reasonably well controlled. However, the children were always tested in classrooms and in the same general atmosphere. The adults were tested in hotel ballrooms, their place of work, in schools and, in a few cases, in their own homes. It is possible that these varying conditions effected the outcome of the adult study.

RESULTS OF THE SECOND INVESTIGATION

Results. An analysis of variance was performed to determine if there were differences between the groups of four subjects, each group reading a different combination. The analysis also tested for differences between the spacing variables. Table XVII shows the mean reading speed for the subjects who read Braille with a given value of each of the spacing variables.

Dot Spacing	.080"	.090"	.100"
Mean	79.39	95.54	96.19
Cell Spacing	.123"	.140"	.160"
Mean	86.04	91.00	93.72
Line Spacing	.163"	.220"	.330"
Mean	90.80	92.23	88.0

Table XVII. The mean reading speed in words per minute for all subjects who read Braille with a given value regardless of the other values with which it was combined.

In this analysis there were no extra-chance differences between specific combinations or between the spacing variables and their interactions. This is the same first analysis that was done on the children's data and the results are the same. The variability between subjects in each group of four subjects probably prevented any differences from appearing. The reader is referred to the children's study for a more detailed discussion of this type of analysis. The summary table appears in Table XVIII

Source	df	SS	MS	F
Dots	2	7595.39	3797.70	1.73
Cells	2	389.49	194.75	
Lines	2	614.12	307.06	
Dots X Cells	4	3574.01	893.50	
Dots X Lines	4	2003.80	500.95	
Cells X Lines	4	768.04	192.01	
Dots X Cells X Lines	8	4001.82	500.23	
Within Cells	79	174624.42	2210.44	

Table XVIII. Summary of Analysis of Variance: total number of words (Adult Study)

Trend Analyses. As in the previous study trend analyses were made of the four successive twenty-five minute reading periods for distance between dots, cells, and lines. The curves for these values were presented in Figures 32, 33, and 34.

Trend Analyses for Dot Spacing. Figure 32 shows the curves for words per minute for the four successive reading periods for dot spacing. Table XIX shows the actual values for each of these points.

Dot Spacing	SUCCESSIVE READING PERIODS			
	1.	2.	3.	4.
.080"	79.1	78.6	81.9	82.8
.090"	96.3	87.8	102.7	95.3
.100"	95.2	90.1	102.4	97.6

Table XIX. The average reading rate in words per minute for each of the twenty-five minute periods for the three dot spacings. (Adult Study)

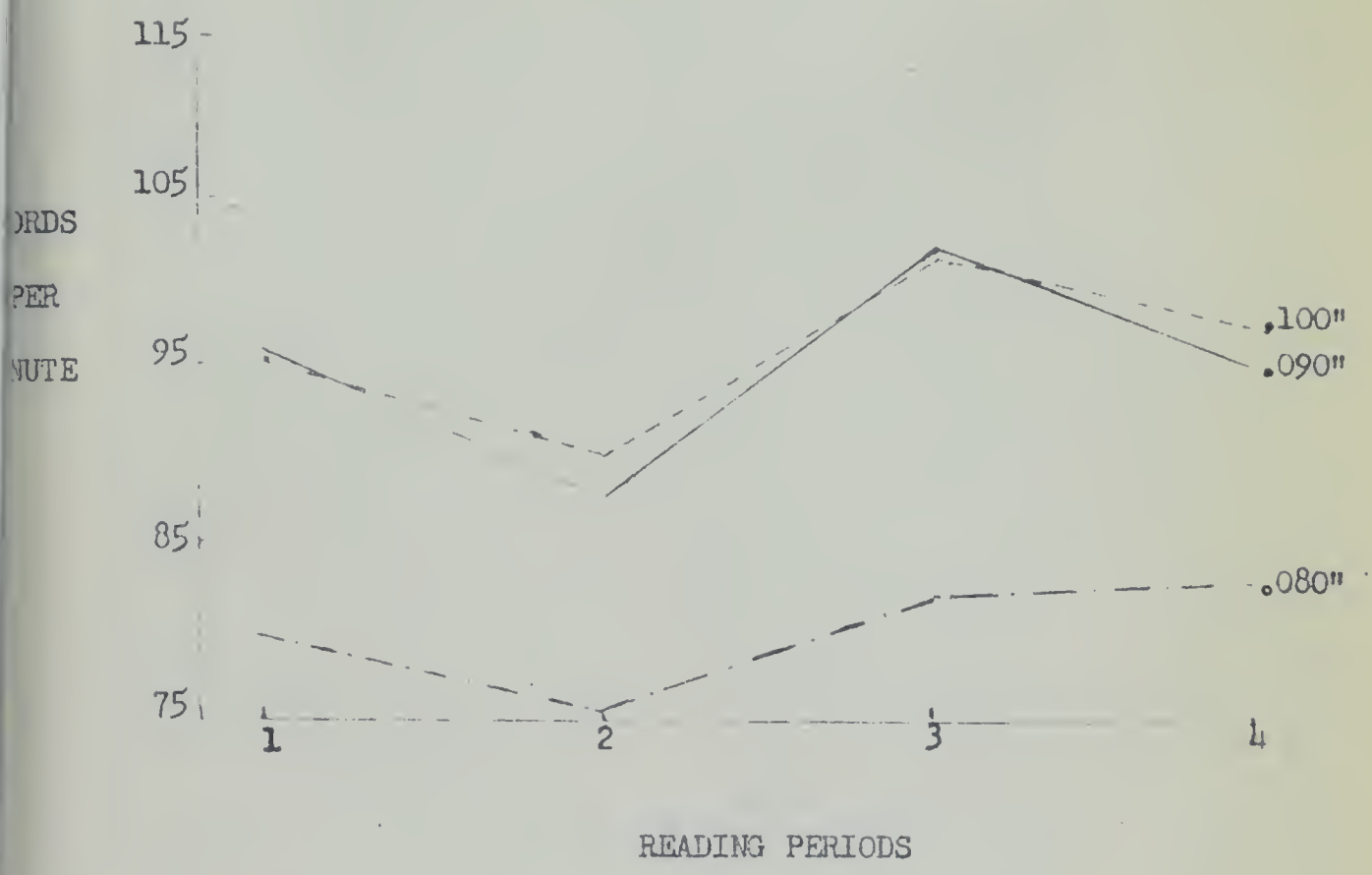

Figure 32. Average number of words per minute at successive reading periods with three values of spacing between dots. (Adult study)

From Figure 32 and Table XIX it can be seen that all readers slowed down during the second twenty-five-minute period and recovered during the first period of the following day. The readers of the .100" and .090" Braille slowed down again in the final period, but the readers of the .080" material showed a slight spurt at the end. However, the .090" and .100" curves are almost identical and are well above the .080" curve at all points.

The trend analyses revealed the following:

1) The curves are not linear.

2) The overall slopes differ significantly.

This is probably due to the final slight rise in the .080" curve in contrast to the drop in the other curves.

3) There is a significant difference between individual means.

4) There is a significant difference between group means.

Table XX is the summary table for this analysis.

Source	df	SS	MS	F
Individual Deviations from Estimation	206	28330.12	137.52	
Group deviations from Estimation	4	175.91	178.98	1.30**
Overall deviations from Linearity	2	4702.59	2351.80	17.10**
Between Individual slopes	103	12148.14	117.94	.86
Between Group slopes	2	94.95	47.48	
Overall slopes	1	1822.21	1822.21	13.30**
Between Individual Means	103	740937.34	7193.57	52.31**
Between Group Means	2	25584.92	12792.46	93.02**

** P = .01

Table XX. Summary of Test for Trend Between Dot Spacings. (Adult Study)

From Figure 30 and Table XXI it can be seen that all readers showed gains during the second (morning-evening) period and continued during the third period of the following day. The readers of the .10" and .05" italic slowed down again in the third period, but the readers of the .05" vertical showed a slight drop at the end. However, the .05" and .10" curves are almost identical and are well above the .05" curve at all points.

The trend analysis revealed the following:

1) The curves are not linear.

2) The overall slopes differ significantly. This is probably due to the slight drop in the .05" curve in contrast to the rise in the other curves.

3) There is a significant difference between typographical means.

4) There is no significant difference between group means.

Table XX is the summary table for this analysis.

Source	df	SS	MS
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Since the Trend Test demonstrated a difference between group means, it seemed advisable to perform two factor analyses of variance between dot spacings of .100" and .080" and between dot spacings of .090" and .080". Both of these analyses demonstrated extra-chance differences, suggesting, as in the study of grade and high schoolreaders, that a dot spacing of .080" is inadvisable. There seems to be no choice between .100" and .090". This was also true in the first investigation. The summaries for these analyses are presented in Tables XXI and XXII.

Source	df	SS	MS	F
Values	1	18517.60	18517.60	9.21**
Intervals	3	3920.30	1306.77	
Values X Intervals	3	720.04	240.01	
Within Cells	276	55027.87	2010.97	
Total		571818.81		**p .01

Table XXI. Summary of Analysis of variance between .080" and .090" Distance between dots. (Adult)

Source	df	SS	MS	F
Values	1	19923.47	19923.47	12.58**
Intervals	3	3113.50	1037.83	
Values X Intervals	3	308.58	102.86	
Within Cells	273	431992.82	1582.91	
Total	280	455338.37		**p . .01

Table XXII . Analysis of Variance Between .080" and .100" Distance Between Dots. (Adult Study).

Trend Analysis of Cell Spacing. The subjects who read Braille with different cell spacings also dropped during the second twenty-five minute period and all recovered during the early part of the second day. However, those readers whose Braille cell spacing was .160" continued to improve on the second day. The .140" and .123" curves both dropped in the final twenty-five minute period. The .160" curve is consistently above the other curves with one exception where the .140" curve crosses it on the third twenty-five minute period. The .123" curve is below the .140" curve with one exception. These trends are illustrated in Table XXIII, and Figure 33.

Cell Spacing	SUCCESSIVE READING PERIODS			
	1.	2.	3.	4.
.123"	85.1	83.5	91.7	85.9
.140"	92.7	81.5	98.9	89.1
.160"	92.7	88.9	96.2	98.6

Table XXIII. The average reading rate in words per minute for each of the twenty-five minute periods for the three cell spacings.

The trend analysis reveals:

1) The curves are not linear.
2) The overall curves are not the same slope.
3) There was a significant difference between individual means.
4) The group means differed significantly.

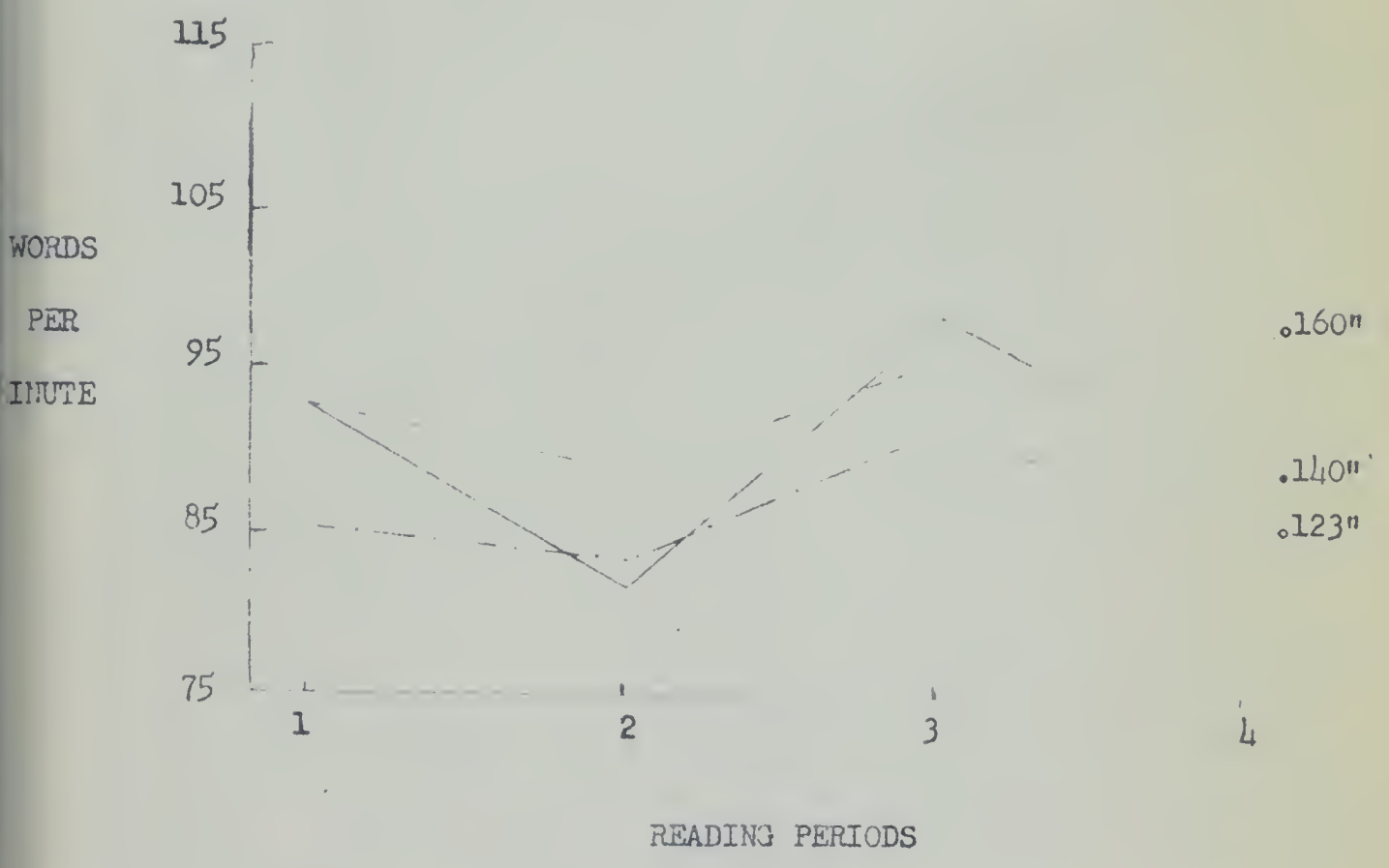

Figure 33. Average number of words per minute at successive reading periods with three values of spacing between cells. (Adult study)

The summary table of the analyses is shown on Table XXIV.

Source	df	SS	MS	F
Individual Deviations from Estimation	206	26799.75	130.10	
Group Deviations from Estimation	4	2246.28	561.57	4.32*
Overall Deviations from Linearity	2	4703.59	2351.80	18.08**
Between Individual Slopes	103	12055.94	117.03	.90
Between Group Slopes	2	189.15	94.58	
Overall Slope	1	1822.21	1822.21	14.01
Between Individual Means	103	762553.74	7403.43	56.91**
Between Group Means	2	3698.52	1984.26	15.25**

*p .05
**p .01

Table XXIV. Test for Trend between cell spacings. (Adult Study)

Since the between group means F was significant it again seemed advisable to calculate two factor analyses of variance. The readers of .160" cell spacing were consistently above the others so analyses were made between .160" and .140" and between .160" and .123". In neither case did any of the F ratios reach the .05 level, although p was equal to .20 for the latter analysis. Tables XXV and XXVI are the summaries of these two analyses of variance.

Source	df	SS	MS	F
Values	1	913.08	913.08	--
Intervals	3	5799.42	1933.14	--
Values X Intervals	3	1551.92	517.31	--
Within Cells	280	589840.58	2106.57	--
Total	287	598305.00		

Table XXV. Analysis between .140" and .160" cell spacing. (Adult Study)

Source	df	SS	MS	F
Values	1	3967.56	3967.56	2.02
Intervals	3	2530.28	840.09	
Values X Intervals	3	688.99	229.66	
Within Cells	272	532383.79	1957.29	
Total	279	539560.62		

Table XXVI. Analysis of variance between .160" and .123" cell spacing. (Adult Study)

Here, then, we have a case in which there is a significant difference when all curves are considered, but no significant difference between any two curves. From inspection of the data it would seem as if cell spacing .160" is superior to .140" and .140" is superior to .123". This finding represents the only real difference between the children and adult readers. The children read .123" at a significantly greater rate than they read .160" as indicated by the trend analysis

Trend Analysis of Line Spacing. Once more all readers dropped during the second twenty-five minute period. They all improved at the outset of the second day and all slowed down during the last twenty-five minute period.

The curve for the readers of Braille with line spacing of .300" shows much steeper rises and falls than the others. The .220" and .163" curve parallel each other, but the .220" curve is consistently above the .163" curve as well as the .300" curve. These data are presented in Table XXVII and Figure 34.

Line Spacings	SUCCESSIVE READING PERIODS			
	1.	2.	3.	4.
.163"	90.6	87.2	94.6	91.2
.220"	91.4	89.2	97.0	94.1
.300"	88.8	77.5	95.4	88.6

Table XXVII. The mean reading rate in words per minute for subjects who read different line spacings. (Adult Study)

The Trend analysis demonstrated the following:

1) The curves are not linear.
2) The overall slopes differ significantly.

This is probably accounted for by the way in which the .300" curve differs from the other two.

3) The group means differ significantly.

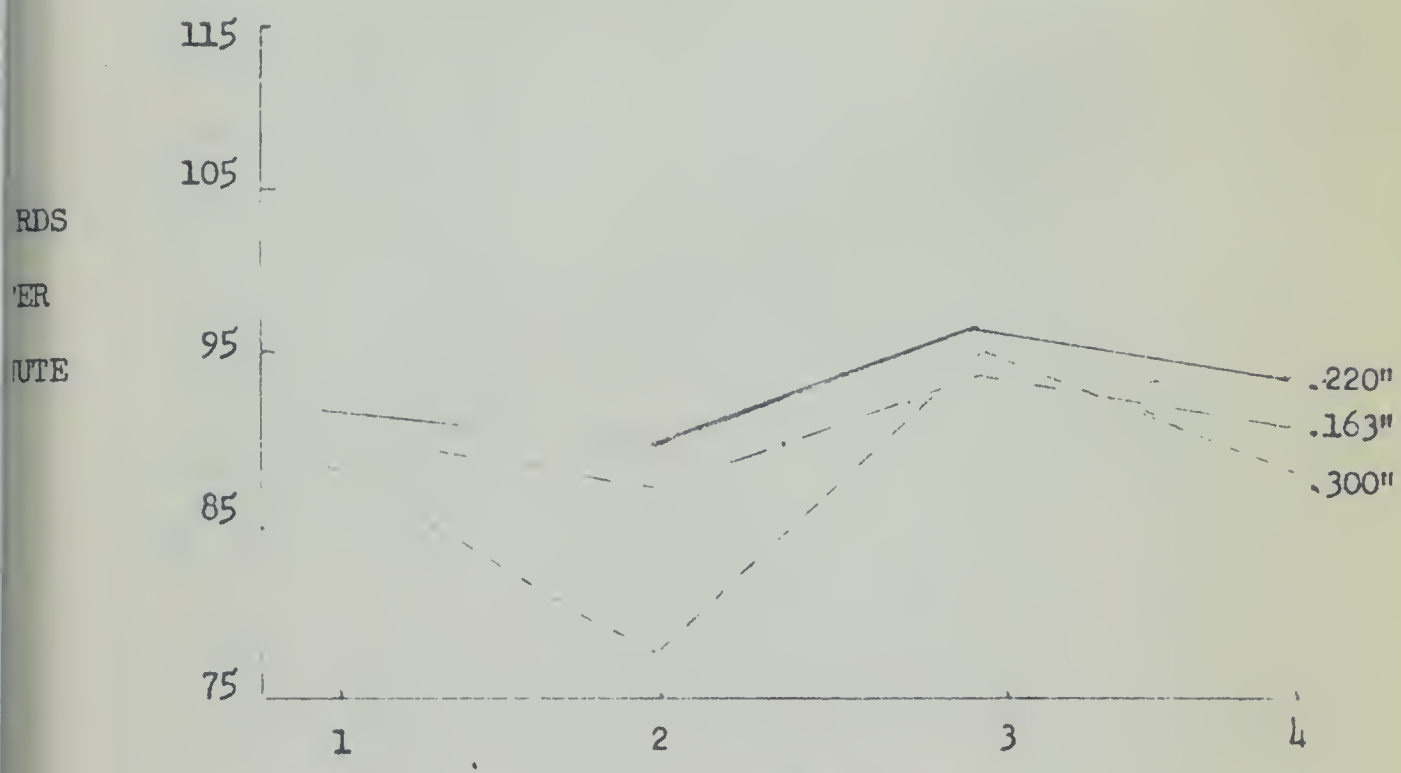

Figure 34. Average number of words per minute at successive reading periods with three values of spacing between lines. (Adult study)

Table XXVIII is the summary of this trend analysis.

Source	df	SS	MS	F
Individual Deviations from Estimation	206	27758.68	134.75	
Group Deviations from Estimation	4	1287.35	321.84	2.39
Overall Deviations from Linearity	2	4703.59	2351.80	17.45**
Between Individual Slopes	103	12115.34	117.62	.87
Between Group Slopes	2	127.75	63.88	.47
Overall Slope	1	1822.21	1822.21	13.52**
Between Individual Means	105	764486.98	7422.20	55.08**
Between Group Means	2	2035.28	1017.14	7.55**

**p = .01

Table XXVIII. Summary of Trend analysis for Line Spacing. (Adult Study)

Again the between group means F was significant. Two factor analyses of variance were made between .220" and .163" and .300", the F ratios did not approach significance in either case. The summary tables are not included. From inspection of the data (Table XXVII) and Figure 34) it seems logical that most of the overall significance comes from the superiority of both .220" and .163" over .300". And certainly the means for the line spacing of .220" are above either of the others at all successive reading periods.

GENERAL CONCLUSIONS OF THE CHILDREN AND ADULT STUDIES

SOME INTERPRETATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The problem was to determine whether different values of the three spacing variables affected readability. The first simple analysis of variance failed to show any difference for any of the variables or Braille combinations. This was true for both investigations. It was pointed out that the great variability of scores within Braille combinations masked possible differences. This variability was forced by selecting subjects from each quartile for each group of subjects.

The more sensitive trend analyses, however, demonstrated some interesting differences. Concerning dot spacing, adults read Braille whose dots within cells are .080" apart less rapidly than Braille whose dots are either .090" or .100" apart. There is no choice between the latter two spacings. This is exactly the same conclusion that was reached in the investigation which employed school children as subjects. The major difference between the adult readers and the children occurred in the analysis of cell spacing. The results were essentially opposite. Adults read Braille whose cell spacing was .160" most rapidly and the .123" spaced Braille least rapidly although significance was only obtained when all three values. (.160", .140", and .123") were considered simultaneously, not when any two of the spacings were compared separately. The children read Braille whose cell spacing was .123" at a greater rate than they read material whose cell spacing was .160".

This finding was statistically significant. The difference between .140" and .123" was not significant. If further research is to be done it would seem worthwhile to discover if this difference between children and adults is consistent. The logic for this particular finding is not too clear to the authors, although some speculations can be made. Perhaps school children are more adaptable to changes in Braille, or the size of the finger may be a major factor. Of course children's fingers are smaller and smaller cell spacing should interfere less with discriminability between Braille cells. If this were true their faster reading could be accounted for by the fact that more words are read per inch of finger movement. On the other hand perhaps the present cell spacing of .160" is the most desirable for adults. An interesting research possibility would be to simultaneously vary cell spacing and finger size.

The adults read Braille whose line spacing was .220" (present standard) faster than they read the smaller spacing of .163" and the larger spacing of .300". This finding was only statistically significant when all three values were considered simultaneously. The children also read more rapidly when the line spacing was .220". In this case .220" material was read significantly faster than the .140" and the .300" Braille when separate two factor analyses of variance were computed. For line spacing, then, the children and adult readers apparently perform most efficiently with the present specifications.

Combining the data the most logical Braille combination for adults would be: dot spacing, .090" or .100"
cell spacing, .160"
line spacing, .220"

.090", .160" and .220" are the present specifications.

For children, the findings indicate that the following are the superior combinations:

dot spacing, .090" or .100"
cell spacing, .123" or .140"
line spacing, .220"

It must be remembered that other values of each of the variables could have been selected. The fact that the middle values were superior for two of the variables for both children and adults would suggest that greater extremes would not have been read at a greater rate. Slight deviations from these middle values could very well be read as fast or faster than the values employed in the study. It is possible that a number of other values for cell spacing would be read at as great or greater rate than any of the values employed in this study.

Another result, not previously stated, requires some interpretation--the subjective reports by the readers concerning the kind of Braille they were reading. The subjects were given no information concerning the nature of the Braille they were reading. At the end of the last reading period they were asked questions about the distance between the dots, cells, and lines and they were asked whether they preferred the Braille they were reading to standard Braille. Many subjects reported that one or more of the spacing variables were closer than standard Braille when this was not actually the case. The reverse seldom occurred.

The dots on all Braille were .015" high. Standard Braille is usually higher. There may have been confusion between the smallness of the dots and the spacing between them. An unpublished study by Meyers and Ashcroft demonstrated clearly that differences in dot height as low as .001" can be discriminated by blind readers. A study of Readability of Braille as a function of dot height seems to be in order.

Some other possible research problems are:

1) An investigation of the most effective spacing variables as a function of reading ability.

2) An investigation of the most desirable spacing values for beginning readers, both children and adult. This is, of course, related to, but not the same as the above suggestion.

3) Employing fairly large numbers of subjects, compare readability of just a few combinations. Namely, those that contain values which were read rapidly in the present study, but whose values did not differ significantly. For instance, the children read combinations which contained a cell spacing of .123" faster than they read combinations which had cell spacings of .140", but not statistically significantly faster. If thirty children read a combination whose spacings were .090" - .123" - .220" and thirty read a combination of .090" - .140" - .220", significance differences should appear if they exist. As a matter of fact the results of cell spacing seem to be least clear for both adults and children and this problem should be investigated further.

4) Meticulous care was taken in printing the Braille for this study, emphasis was placed on uniformity of dot height and care was taken to prevent the dots from breaking through. An investigation could be undertaken to determine whether uniformity of dots affects reading rate.

FINAL SUMMARY

An attempt was made to determine, within specified limits, which values of three spacing variables of Braille print are most readable. The spacing variables were distance between dots in Braille cells, distance between Braille cells and distance between Braille lines. The values employed in the study were:

dot spacing: .080", .090" and .100"
cell spacing: .123", .140" and .160"
line spacing: .163", .220" and .300"

The underlined values represent the present specifications.

The reading material was the Black Arrow by Robert Louis Stevenson. Two hundred and seventy-five grade and high school children (lower limit was the fifth grade) and one hundred and sixty-seven adults read standard Braille for thirty minutes from chapters twelve and thirteen of the Black Arrow. The purpose of this initial part of the study was to obtain initial scores for all subjects. The instructions emphasized both speed and accuracy. The average reading rate of children for this material was sixty-eight words per minute; for adults 91.69 words per minute. All subjects who showed poor comprehension were eliminated from the study. The reading scores in words per minute were plotted in two frequency distributions, one for children and one for adults. Each distribution was divided into quartiles, each quartile representing different and successive ranges of reading speeds. Twenty-seven groups of four children were selected from the childrens' distribution. Each of the four children in a group were selected from a different quartile, and the mean reading speed of each group was made to equal seventy

words per minute plus or minus one. In a similar manner twenty-seven groups of four adults were selected. Each adult in a group was selected from a different quartile; however, no attempt was made to make the average scores exactly the same in each group of adults.

There were twenty-seven possible combinations of Braille dot, cell, and line spacings. Each group of four children was assigned to one of these combinations and each group of adults was assigned to a combination. All subjects read their assigned Braille for two fifty minute periods on two successive days. The instructions again emphasized speed and accuracy and the importance of not skipping words. The experimenters recorded the time at the end of each page. Comprehension questions were asked at the end of the second fifty minute period. Subjects who failed to answer fifty percent of questions on material read were discarded and new subjects substituted from the pool of equation subjects. Questions concerning their reaction to the Braille were also asked of all subjects.

The data for the children and adults were analyzed separately. Several kinds of analyses were made. From these analyses the following Braille specifications seemed superior:

	For Children	For Adults
dot spacing	* .090" or .100"	* .090" or .100"
cell spacing	.123" or .140"	* .160"
line spacing	* .220"	* .220

* Present standard spacing

Several interpretations and suggestions for further research were made.

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APPENDICES

1. POSSIBLE COMBINATIONS OF THREE VALUES OF THREE BRAILLE DIMENSIONS

Interdot spacing -- .080, .090, and .100 inches
Intercell spacing--(distance from center to center of adjacent dots in adjacent cells) .123, .140, and .160 inches.
Interline spacing--(distance from center to center of adjacent dots (in adjacent cells) in adjacent lines) .163, .220, and .300 inches.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Interdot	.080	.080	.080	.080	.080	.080	.080	.080	.080
Intercell	.123	.123	.123	.140	.140	.140	.160	.160	.160
Interline	.163	.220	.300	.163	.220	.300	.163	.220	.300

	10.	11.	12.	13.	14.	15.	16.	17.	18.
Interdot	.090	.090	.090	.090	.090	.090	.090	.090	.090
Intercell	.123	.123	.123	.140	.140	.140	.160	.160	.160
Interline	.163	.220	.300	.163	.220	.300	.163	.220	.300

	19.	20.	21.	22.	23.	24.	25.	26.	27.
Interdot	.100	.100	.100	.100	.100	.100	.100	.100	.100
Intercell	.123	.123	.123	.140	.140	.140	.160	.160	.160
Interline	.163	.220	.300	.163	.220	.300	.163	.220	.300

II. INSTRUCTIONS TO CHILDREN - EQUATING STUDY

We are studying Braille to see if we can improve it in some way. We would like to have you help us. We want you to read some Braille material silently. Read the material as fast as you can without skipping any words. You will be asked to read a few pages. This has nothing to do with your school work. We do not care if you are not as fast a reader as someone else. However, we want you to read as quickly as you can. The material you will read is an interesting adventure story, and I think you'll enjoy it.

I will call your name, you raise your hand and I will give you the material you will read. Keep the booklet closed until I tell you to open it. Be sure not to open the booklet until I tell you all to do so. I want you to start reading the story at the same time.

When I tell you to "start", open your booklet and begin reading. Read as fast as you can until I tell you to stop. Be sure not to skip any words. When I tell you to stop, keep your finger on the word you are then reading until I come by and mark your place.

I will give you another booklet which contains 20 questions in Braille on the story you have just read. Are there any questions?

						79								
						79								
					59	79								
					58	79								
					58	79								
					58	79								
					58	78								
					58	69	78							
					58	69	77							
				49	57	69	77							
				49	57	69	77							
				48	57	69	77							
				48	57	69	77	89						
			29	47	57	69	76	89						
			29	39	47	56	68	76	89					
			28	39	46	56	67	76	88					
			28	38	46	56	67	75	88					
			28	38	45	55	66	75	87	98				
			27	37	45	55	66	75	86	97				
			27	37	45	55	65	75	86	96				
			27	37	45	55	65	74	86	95				
			26	36	44	54	64	74	86	95				
			26	35	44	54	64	74	84	95				
			26	34	43	54	64	73	84	95	109		129	
			26	34	43	54	64	73	83	93	108		128	
			24	32	43	54	64	73	82	93	106	117	127	
			24	33	43	53	63	73	82	93	105	114	126	
		18	24	33	43	53	62	72	82	92	104	114	126	
		17	24	32	42	52	62	72	82	91	103	114	126	
		15	23	32	42	51	62	72	82	91	103	114	125	136 195
		15	23	32	41	51	61	72	81	91	103	113	125	136 195
		14	23	32	41	51	61	72	80	90	102	112	124	135 169
		14	21	31	41	50	60	72	80	90	101	112	122	134 161
09	13	20	30	41	50	60	71	80	90	101	112	121	132	154
05	10	20	30	40	50	60	70	80	90	100	111	121	131	153

00	10	20	30	40	50	60	70	80	90	100	110	120	130	140
to	to	to	to	to	to	to	to	to	to	to	to	to	to	to
09	19	29	39	49	59	69	79	89	99	109	119	129	139	195

III. FREQUENCY DISTRIBUTION OF CHILDRENS SCORES ON EQUATING MATERIAL

MEAN READING RATES WITH STANDARD BRAILLE SPECIFICATIONS--
CHILDREN

080-123-163	080-140-300	090-123-163	090-123-300	100-160-220
44*	43	20	33*	30
46	43	69	63	66
66	69	90	82	82
125	125	101	103	98*
281	280	280	281	276

100-140-163	100-160-163	090-123-163	080-140-163	080-123-220
35*	26	24	29	29
57	60*	67	62	62
76	86	86	88	80
126*	103	103	100*	109
294	275	280	279	280

080-140-220	090-160-220	090-140-300	080-160-300	100-123-163
28	24	24	26	42
64	65	62	67	45
80	86	90	81	74*
108	105	104	97*	124
280	280	280	271	285

100-160-300	080-123-300	100-123-220	090-160-163	090-140-220
36	39	41	37	42
58	53	54	55	46
72	75*	73	71	70
114	112	112	117	122
280	279	280	280	280

100-123-300	090-160-300	080-160-220	100-140-300	080-160-163
41	41	34	34	33
50	45	49	55	48
68	73	83	77	86
121	121	114	114	113
280	280	280	280	280

100-140-220	090-123-220
32*	32
51	54*
87	84
111	112
281	282

IV. Individual scores and group total for each of the twenty-seven combinations of Braille specifications. The total for each group was originally 280 words per minute.

* Substitute Scores.

V. INSTRUCTIONS FOR EXPERIMENTAL STUDY -- 1st Session.

As you will remember, we are studying Braille, and you have already participated in the first part of our study. Today, we want you to help us with a second part of the study by reading some more Braille material. silently. This reading will be a little longer than last time, and I want to remind you again to not talk to me or anyone after you start, and also to not take any breaks for rest during the reading period.

We want you to read the material as fast as you can without skipping any words. We don't care if you are not as fast a reader as someone else, however, we do want you to read as quickly as you can.

The booklet will be placed before you in the correct reading position, and when I tell you to start, open your booklets and begin reading. Read as fast as you can until I tell you to stop. When I tell you to stop, keep your finger on the word you are then reading until I mark your place. Be sure to keep your finger on the word you are then reading. After you have finished, I will read some questions to you on the material you have just read. Do you have any questions?

2nd Session

Today we'll continue reading where we stopped yesterday. I will open your booklets and place your finger on the word at which you stopped yesterday. Do not move your finger until I tell you to "start".

When I tell you to "start", begin reading as fast as you can without skipping words until I tell you to "stop". When I tell you to stop, keep your finger on the word you are then reading until I mark your place.

After you have finished today, I will reas some questions to you on the material you have just read.

If you happen to finish this booklet before the reading time is up, I will have another booklet opened for you to read, which is the second part of the story. Do not say anything, and make the change in booklets as quickly and as quietly as possible.

Do you have any questions?

VI. READING SPEED OF ADULTS IN WORDS PER MINUTE FOR TWENTY-SEVEN EXPERIMENTAL COMBINATIONS

080-123-163	080-140-300	080-140-163	080-123-300-	080-140-220
71	127	92	109	72
123	40	69	40	84
91	49	166	76	51
22	89	64	69	129
307	305	391	294	336

080-160-300	080-123-220	080-160-163	080-160-220	090-140-163
57	91	29	48	26
69	125	45	81	97
29	40	88	144	76
95	256	168	34	136
250		330	307	335

090-123-300	090-123-163	090-160-300	090-140-300	090-160-163
41	64	49	60	75
85	53	174	102	86
167	179	130	162	180
80	165	103	80	44
373	461	456	404	385

090-140-220	090-123-220	090-160-220	100-160-220	100-140-163
62	89	67	114	47
143	180	112	112	97
57	68	35	97	64
88	50	169	95	168
350	387	383	418	376

100-160-163	100-123-163	100-160-300	100-123-220	100-123-300
170				
118	95	55	55	76
48	74	177	82	52
79	110	88	129	101
415	279	111	68	108
		431	334	337

100-140-300	100-140-220
114	94
90	92
92	218
24	56
321	460

00 to 09	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	60 to 69	70 to 79	80 to 89	90 to 99	100 to 109	110 to 119	120 to 129	130 to 139	140 to 149	150 to 159	160 to 169	above 169
										109							
										109							
										109							
										108							
										108							
										108							
								88		108							
								88		107							
								88		107							
						69		88		107							
						68		87		107							
						68		87		107							
						68		87		106							
						67		87		105							
					59	67		86	99	105							
					57	67		86	99	104							
					57	67	79	85	99	104	118						
				46	57	65	78	85	97	104	118						
		29		46	57	64	75	85	97	104	117				159		
		28		46	56	62	74	84	96	103	117		138		158	168	
		28	37	44	54	62	72	84	95	102	115		138		155	167	
		27	36	44	53	62	72	84	94	102	114	128	138	149	155	166	
		25	35	44	53	62	71	84	93	101	113	127	137	148	154	166	
		24	35	43	53	61	71	83	92	101	112	127	134	148	151	165	199
09		23	34	42	53	61	70	82	91	100	112	126	132	143	150	160	192
05		22	33	40	50	60	70	80	91	100	110	123	130	142	150	160	184

VII. DISTRIBUTION OF READING RATES OF ADULT SUBJECTS FOR THE EQUATING MATERIAL.

COMBINATION NUMBER	AVERAGE DOT HEIGHT IN INCHES
100-240-420	.01515
80-250-380	.01632
90-213-480	.01667
100-240-363	.01685
90-250-480	.01466
90-230-380	.01403
80-203-380	.01635
100-260-420	.01566
90-213-400	.01442
90-230-400	.01436
80-220-325	.01801
80-220-500	.01716
100-240-500	.01466
90-213-343	.01653
90-230-343	.01470
100-260-500	.01567
100-223-363	.01709
100-223-500	.01551
100-223-420	.01595

.01556 - Average Dot Height for all Dots measured.

VIII. Dot Height. 10 dots from each of the above combinations were randomly selected and their heights measured with an Optical Comparator.

PRELIMINARY INVESTIGATION I

Summary of an investigation of the ability of subjects to detect differences in the height of Braille dots.

Subjects: Sixteen students of the Kentucky School for the Blind.

Apparatus and Procedure: Stimulus sheets were prepared by the American Printing House for the Blind. Each sheet had 412 pairs of Braille dots. Each pair of dots had a top radius of either .015", .020", .025", or .030", and each pair differed in height by .01" or more depending on the assigned values.

For tip radius .015" it was possible to vary the height from .005" to .010" in .001" step intervals, without breaking the paper. Similarly for tip radius .020", it was possible to vary the height from .005" to .011". The maximum height for tip radius of .025" was .015, and for tip radius .030" the maximum height was .017". For each tip radius every height was paired with itself and every other height twice. Thus height .005" was paired twoic with heights .005", .006", .007", .008", .009", and .010". In like manner height .006" was paired with itself and each of the other heights twice. The same procedure was followed for each of the other tip radii. The order of presentation of the pairs of dots was randomized. The task of the subject was to report whether the second of each pair of dots was higher or lower than the first. Each response was recorded on a prepared data sheet. A forced choice technique was employed; subjects could not report that the second dot was the same as the first.

The errors were tabulated and the data analyzed.

Results: I. Total errors The mean number of errors per subject was 45.00 or 13.3%. The range was from 22 to 90 errors. Since there were 338 pairs (excluding pairs in which the heights were the same), the expected mean chance frequency would be 169 errors. Discrimination was considerably better than that expected by chance. P .01.

II. Errors on pairs of dots which differed by .001" The mean number of errors on pairs whose dots differed by .001" was 21.0. There were 66 pairs on each stimulus sheet. Thus on the average the subjects judged 45 pairs correctly or 68.2%. This is statistically significant (P .01). This is the most important finding of the study.

Table 1 shows the errors made by subjects as a function of the difference in the height of dots in pairs. It demonstrates clearly the decreasing number of errors made as the height difference increases.

TABLE 1

(Table 1 shows errors and % errors made by the 16 subjects for pairs which differed from .001" to .012". All tip radii are combined.)

Difference in pairs	Total no. of pairs judged	Errors made	% Error
Pairs differing by .001"	1056	336	31.8
" " " .002"	928	197	21.3
" " " .003"	800	105	13.1
" " " .004"	672	73	10.9
" " " .005"	544	20	03.7
" " " .006"	416	7	01.7
" " " .007"	320	6	01.9
" " " .008"	256	2	00.8
" " " .009"	192	3	01.5
" " " .010"	128	0	00.0
" " " .011"	64	1	01.6
" " " .012"	32	1	03.1

III. Errors as a function of the tip radius There was only a suggestion of a trend in ability to discriminate dot height as a function of the tip radius.

For tip radius .015" subjects made 16.9% errors
" " " .020" " " 21.0% "
" " " .025" " " 12.8% "
" " " .030" " " 11.2% "

Although these data suggest that the two larger tip radii facilitate dot height discrimination, with the exception of radius .020" there is very little difference. None of these differences is statistically significant.

IV. Errors as a function of the position on the height continuum at which the subject discriminates The question asked here is whether the subject discriminates more or less accurately between dots whose heights are .005" and .006" than dots whose heights differ by the same amount but which are higher, such as .009" and .010" or .015" and .017".

There was no trend. Discrimination between pairs at the low levels was no better or worse than discrimination at the high levels. Table 2 presents these results for pairs whose height differed by one.

TABLE 2

Errors of .001 as a function of the height level at which the pairs are judged. All tip radii are combined. Sixteen subjects.

Height of pairs	No. of pairs judged	No. of errors	% Error
5 - 6	128	44	34.4
6 - 7	128	48	37.6
7 - 8	128	40	31.2
8 - 9	128	36	28.1
9 - 10	128	40	31.2
10 - 11	96	27	27.1
11 - 12	64	14	21.9
12 - 13	64	23	35.9
13 - 14	64	19	30.0
14 - 15	64	19	30.0
15 - 16	32	16	50.0
16 - 17	32	8	25.0

V. Time errors In other sensory areas it has often been observed that when subjects are presented two successive physically equal stimuli, they consistently judge the second stimulus as more intense than the first. The analogy in this study would be that subjects would call the second of the two equal dots higher than the first. This did not occur. Although some subjects made fairly consistent errors in one direction, others made errors in the other direction. The final effect was not significant.

PRELIMINARY INVESTIGATION II

Purpose: To discover if there is any difference in reading speed and comprehension of Braille printed in full interpoint as opposed to Braille printed in semi-interpoint.

The major study is to include three variables: distance between dots within the cell, distance between cells, and distance between lines. There would be considerably more latitude for variation of distance between lines if full rather than semi-interpoint were used. Also, if full interpoint proved practical, it would be possible to print several more lines per page. There are apparently no technical difficulties in printing full interpoint Braille.

Subjects: Seven female adult Braille readers and one male adult Braille reader.

Design: Two 1400-word passages were used, one selected from Patterns of Culture by Ruth Benedict, and one from Gods, Graves, and Scholars by C. W. Ceram. Four copies of each were printed in full interpoint and four copies of each in sem-interpoint. Each subject read both passages but the passages and the kind of interpoint were counter-balanced.

Letting P1 be passage 1 and P2 be passage two, and f be full interpoint, and s be semi-interpoint, the following table indicates the design:

Subjects	1 & 5	2 & 6	3 & 7	4 & 8
Passage read first	P1s	P1f	P2s	P2f
Passage read second	P2f	P2s	P1f	P1s

It can be seen that with this design both the difference in the difficulty of the two passages and any serial effect are controlled. If any difference exists in speed of reading full interpoint vs. semi-interpoint, it should appear in the difference between the mean reading time of full interpoint passages and the mean reading time of semi-interpoint passages.

Procedure: The investigation was carried out in one day by two experimenters. Each subject was given the following instructions: "I am going to ask you to read two brief passages. Read them as quickly as you can without skipping. I will ask you a few questions about the material when you have finished, but remember to read as quickly as you can without skipping. Start reading when I say go." There were eight pages in each passage and the reading time for each page was recorded. At the end of each passage, the subjects were asked ten questions about the content and the asnwers were recorded.

At the end of each session the subjects were asked to scan a page or two of each passage and to report any differences in the print.

Results:

I. Reading Times

The mean reading time for the semi-interpoint passages was 17 minutes and 4.5 seconds. The mean reading time for the full interpoint passage was 17 minutes and 5.0 seconds. The difference is extremely small and no statistical test is necessary. The following table presents the reading times of each subject:

Subject	Semi		Full	
	Minutes	Seconds	Minutes	Seconds
1	19	51	24	02
2	13	36	12	35
3	11	42	12	35
4	11	07	12	41
5	15	39	15	03
6	25	41	23	20
7	18	45	17	43
8	20	15	19	01
Total times	136	36	136	40
Mean time	17	04.5	17	05.0

II Comprehension

The number of correct answers for each passage was recorded. The mean number of correct answers for the full interpoint passages was 8.250 and the mean for the semi-interpoint passages was 8.125. The following table presents the breakdown by subjects:

Subject	Correct Answers-Semi	Correct Answers-Full
1	8	10
2	9	9
3	10	8
4	8	9
5	7	7
6	9	9
7	5	9
8	9	8
Total	65	66
Mean	8.125	8.250

Again the difference is very small and no statistical test is necessary.

III. Ability of subjects to detect differences in the two types of Braille

All subjects responded in a vague manner. A few said that one or the other was sharper but there were no consistent comments.

Conclusions:

The results of the experiment demonstrate that all subjects are able to read both kinds of Braille equally fast and learned each equally well. Therefore, the experimenters recommend that the major study be done with all pages printed in full interpoint.

The Influence of Type Characteristics on Braille Reading[1]

Introduction

Ordinary printing comes in different sizes and styles and a sighted reader encounters many of these during the course of an ordinary day. For blind persons who read Braille printing, there is little variation in the size and form of the printing. Most Braille printing has these standard characteristics: dot spacing .090 inches (distance between dots within the Braille cell); cell spacing .160 inches (horizontal distance between adjacent cells); line spacing .220 inches (vertical distance between lines).

The effect of the characteristics of ordinary printing on readability of visual materials has received considerable investigation. There has been comparatively little investigation, however, of the effects which Braille printing characteristics have on its readability.

A rather elaborate investigation of certain characteristics of Braille printing has been reported recently by Meyers, Ethington, and Ashcroft (1). Twenty-seven different types of Braille printing and 108 adult blind Braille readers were used in one part of the investigation. The second part of the

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1 This investigation was planned by Mr. Virgil Zickel and Dr. Samuel Ashcroft, of the American Printing House for the Blind and the late Dr. Ernest Meyers of the University of Kentucky. It was supported by a contract between the American Printing House for the Blind and the Kentucky Research Foundation. The experimentation and statistical analysis were done by Mr. James Clark who was employed as research assistant for this project. Actual experimentation was carried out in Chicago where 127 blind braille readers were used as subjects. This report has been prepared by Mr. Clark and Dr. James Calvin.

investigation used 108 blind children as subjects. The results suggested that the following characteristics make Braille printing more readable: (1) dot spacings of .090" or .100" were superior to dot spacing of .080"; (2) cell spacing of .160" was superior to cell spacings of .123" and .140"; (3) line spacing of .220" was superior to line spacings of .163" and .300". This was an exploratory investigation and a wide variety of types of Braille printing (27 different types) were used. This permitted only four subjects for each of the 27 different printing types.

This is a report of a second investigation which was planned to use a small number of printing types (five) and a larger number of subjects (twenty) for each group. The five types of Braille printing used are indicated in the table below:

	Conventional Description			Description Used in This and Previous Investigation		
	Dot Space	Cell Space	Line Space	Dot Space	Cell Space	Line Space
(a)	.090"	.250"	.400"	.090"	.160"	.220"
(b)	.090"	.230"	.400"	.090"	.140"	.220"
(c)	.090"	.213"	.400"	.090"	.123"	.220"
(d)	.080"	.240"	.380"	.080"	.160"	.220"
(e)	.080"	.203"	.323"	.080"	.123"	.163"

These particular combinations were selected for the following reasons:

(a) These are the specifications for "standard Braille". This combination was found most readable by adults in the first investigation.

(b) This was read rapidly (but not most rapidly) by adults in the first investigation. If found to be easily readable, its printing would be economical.

(c) This combination was found most re dable for children subjects in the first investigation.

(d) This combination produced one of the slower reading rates in the first investigation.

(e) This combination would yield the largest number of Braille characters on a page. It was read relatively slowly by adults and children in the first investigation.

Procedure

A preliminary reading ability test was given to 127 blind persons. The material was chapters 12 and 13 from the book, The Black Arrow, by Robert Louis Stevenson, and it was embossed in standard Braille. All subjects were instructed to read as much of the material as possible without skipping words and they were told that they would be asked questions on the material they were to read. At the end of a 30-minute reading period, comprehension of the material was tested by a list of twenty questions of the multiple-choice type.

Of these 127 subjects from the preliminary sessions, 100 were used as subjects for the main part of the experiment. These 100 subjects were assigned randomly to the five experimental groups. The remaining 27 persons were eliminated from the experimental analysis for the following reasons: (1) failure to comprehend at least 50 per cent of the preliminary material, as indicated by the comprehension test; (2) some subjects repeatedly fell asleep; (3) some subjects manifested disturbing spasms; (4) some subjects showed overt evidence of anxiety which lead to behavior which seemed to disrupt their reading; (5) failure to return for one of the experimental sessions; (6) failure to continue reading during the timed experimental sessions; (7) and finally, random elimination to reduce each group to 20 subjects.

As described above, there were 20 subjects in each of the five groups indicated in the table on page 2. The experimental periods consisted of two fifty-minute sessions on successive days for each subject. The material used

was chapters 1-8 of The Black Arrow. During each session the experimenter recorded the time at the end of each alternate page. This permitted a measure of each subject's reading speed.

RESULTS

Initial Reading Speeds

There were not differences, except small ones which could be attributed to chance, in the initial reading speeds for the five groups of subjects. These were determined from the preliminary reading ability test. Group means and measures of variability are presented in Table I. From inspection of Table I it might appear that the .080"-.123"-.163" group had superior reading ability (91.09 words per minute) at the beginning of the experiment. However, statistical investigation by means of the analysis of variance technique (Table II) showed that these differences among the five groups are not large enough to be considered significant; they could have arisen from chance fluctuations. From this, it would seem reasonable to conclude that the random procedure of assigning subjects to the five experimental groups resulted in groups whose initial reading ability was essentially the same.

A distribution of reading abilities for all subjects (100) used in the experiment is shown in Figure 1. Inspection of this diagram indicates a wide range of reading abilities among the subjects used and the shape of the distribution (bell shaped) suggests that the subjects are probably a representative group of blind Braille readers. Inspection of Figure 1 suggests that the distribution follows the pattern of the "normal distribution" which is usually found when a representative group is plotted for some human ability. The obtained distribution appears from inspection to be

TABLE I

Reading Speeds During Preliminary Test of Reading Ability

Group	Mean Reading Speed	Standard Deviation
090-160-220	78.59 words per minute	48.05
090-140-220	67.01 words per minute	39.64
090-123-220	74.38 words per minute	39.50
080-160-220	62.23 words per minute	32.34
080-123-163	91.09 words per minute	35.18

TABLE II

Analysis of Variance

Reading Speeds During Preliminary Test of Reading Ability

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	F
Printing Types	9967.49	4	2491.87	1.61
Between Subjects Treated Alike	146788.59	95	1545.14	
Total	156756.08	99		

					59														
					59														
					59														
					57														
					57				99										
					57	69			98										
					57	69			98										
					56	67			97										
			38		55	67			96		119								
		28	37		54	67			95		118								
	19	27	36		54	64			93	109	112								
	19	23	35		54	62	79	86	93	107	111								
	17	22	35		51	61	77	86	93	107	111								
	13	22	33	46	51	60	73	85	93	105	111	122			159				
	13	21	30	45	50	60	71	83	93	104	110	121	134	145	151				
9	10	20	30	42	50	60	70	81	90	104	110	121	134	145	151		177	1[illegible]8	
0- 9	10- 19	20- 29	30- 39	40- 49	50- 59	60- 69	70- 79	80- 89	90- 99	100- 109	110- 119	120- 129	130- 139	140- 149	150- 159	160- 169	170- 179	180- 189	

Words per Minute

Figure 1

Distribution of Initial Reading Abilities for 100 Blind Braille Readers

fairly "normal" in shape. No statistical analysis has been performed to verify this, however.

Reading Speeds for the Experimental Materials

Average reading speeds for each of the five types of printing are presented in Table III. Corresponding measures from the previous investigation are also given for comparison. Inspection of these data suggests that the .090"-.160"-.220" combination was the most readable printing used, the .080"-.160"-.220" combination the least readable. In the latter case, however, the group of subjects which received the .080"-.160"-.220" printing was the lowest group in initial reading ability. Is their relatively low reading performance the result of their poor ability or is it because they received inferior printing?

In order to answer the question of whether these five groups differed in reading speed during the experimental sessions, an analysis of variance of the reading speed data was done. The results of this analysis, presented in Table IV, indicate that the differences among the five group means are not large enough to reach statistical significance.

Although the five groups did not differ significantly in their reading abilities in the preliminary test, as has been pointed out already, the differences seemed large enough to be noticeable if not significant. Group .080"-.123".163", the superior group in the preliminary test, read at a mean rate of 91.09 words per minute. In the experimental test, however, this group had dropped to fourth position out of the five groups and the group read at a mean rate of 67.73 words per minute. On the other hand, the poorest group (.080"-.160"-.220") on the preliminary test remained the poorest group on the experimental tests; this group read at a mean rate

TABLE III

Reading Speeds For Five Types of Braille Printing

Printing Characteristics			Mean Reading Speed in Present Investigation	Mean Reading Speed in Previous Investigation
Dot Spacing	Cell Spacing	Line Spacing	20 subjects per group	4 subjects per group
.090"	.160"	.220"	81.81 words per min.	95.75 words per min.
.090"	.140"	.220"	70.98 words per min.	87.50 words per min.
.090"	.123"	.220"	72.59 words per min.	96.75 words per min.
.080"	.160"	.220"	57.07 words per min.	76.75 words per min.
.080"	.123"	.163"	67.73 words per min.	76.75 words per min.

TABLE IV

Analysis of Variance

Reading Speeds During Experimental Sessions

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	F
Printing Types	12780.05	4	3195.01	1.94
Reading Periods	414.83	1	414.83	
Printing Types x Reading Periods	88.07	4	22.01	
Between Subjects Treated Alike	312752.55	190	1646.07	
Total	323035.51	199		

of 62.23 words per minute on the preliminary test and 57.07 words per minute in the experimental tests.

From such comparisons between preliminary tests and experimental tests, it is difficult to make any definite conclusions about differences caused by the different printing types. A statistical technique called analysis of covariance permits, in effect, an adjustment of the data from the experimental sessions so as to equate all subjects for reading ability. It should be possible to use analysis of covariance to answer this question: If all subjects are equal in reading ability, will the difference in print types make any difference in their reading performance? In this way, the effects of differences in reading abilities can be statistically ruled out. This analysis of covariance was done and the results are reported in Table V. This analysis indicates that the five groups do differ significantly in reading performance on the experimental materials (when differences in reading ability have been taken into account).

Mean reading speed for each of the five groups has been adjusted to equate for initial differences in reading ability. These adjusted means are presented in Table VI. From the analysis of covariance described in the preceding paragraph, we know that these adjusted means differ significantly. Inspection of Table VI indicates that the .090"-.160"-.220" and the .090"-.140"-.220" printing types resulted in superior reading performance and that the .080"-.123"-.183" printing type resulted in relatively poor reading performance.

There were two experimental sessions on consecutive days. Each session was fifty minutes in length. Were there any progressive changes in reading speed during a session or between sessions? For example, it is possible that the effects of practice could operate to improve reading

TABLE V

Summary Table

Analysis of Covariance*

Source	SS	df	MS	F	Significance Level
Adjusted sum of squares within combinations	16,411.79	94	174.59		
Adjusted sum of squares between combinations	9,271.42	4	2,317.85	13.27	.01

* Overall mean number of words per minute for the two sessions was used for each subject.

TABLE VI

Adjusted Reading Speeds for Five Types of Braille Printing

Group	Actual Mean Reading Speed	Adjusted Mean Reading Speed
090-160-220	81.81 words per minute	78.15 words per minute
090-140-220	70.98 words per minute	78.11 words per minute
090-123-220	72.59 words per minute	72.85 words per minute
080-160-220	57.05 words per minute	68.65 words per minute
080-123-163	67.73 words per minute	52.42 words per minute

performance. Or, on the other hand, fatigue effects could cause performance to deterioriate.

Information on this question has been obtained by subdividing each session into two halves (first 25 minutes and second 25 minutes). Reading speeds for each half of the two sessions are presented in Table VII and these results are plotted graphically in Figure 2. Inspection of Figure 2 suggests a slight general trend toward improved reading speed between the first and second experimental sessions for all groups of subjects. From graphic inspection this trend appears fairly slight and it is questionable whether the degree of trend is significant. To answer this question of significance, a trend analysis (2) was done and it was found that the degree of trend was significant. This trend analysis is presented in Table VIII.

Immediately following the second experimental session, each subject was asked several questions aimed at discovering his subjective impressions formed while reading his Braille materials. These questions and a tabulation of the answers given by the subjects in each group appear in Table IX.

TABLE VII

Changes in Reading Speed During Experimental Sessions

	Session 1		Session 2	
Group	First Half	Second Half	First Half	Second Half
090-160-220	80.06	78.80	84.45	83.16
090-140-220	70.68	70.47	72.45	70.19
090-123-220	72.19	69.99	74.29	73.73
080-160-220	57.06	53.65	59.42	58.12
080-123-163	68.99	63.88	69.71	68.48

Figure 2

Changes in Reading Rate with Practice

TABLE VIII

Trend Analysis

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	F	Significance
Group Means	25177.67	4	6294.41	373.77	.01
Individual Means	619240.12	95	6518.31	387.07	.01
Overall Slope	334.82	1	334.82	19.88	.01
Between Group Slopes	70.20	4	17.55	1.04	
Between Individual Slopes	4127.66	95	43.44	2.57	.01
Overall Deviation from Linearity	848.38	2	424.19	25.18	.01
Group Deviations from Estimation	231.75	8	28.96	1.71	
Individual Deviations from Estimation	3199.68	190	16.84		
Total	653230.28	399			

Comparison with Results of First Investigation

As described in the introduction to this report, this investigation employed five printing types out of twenty-seven which had been used in the Meyers, Ethington, and Ashcroft (1) experiment. How do the results of the two investigations compare? The mean reading speeds obtained in each experiment are presented in Table III. Comparison of these results appears striking in two ways:

1. In the present investigation, mean reading speed was consistently lower than in the previous investigation. The probable reason for this discrepancy is that a superior group of readers, including many teachers for the blind, were used as subjects in the previous investigation. It seems likely that the subjects in the present investigation were a more representative group of Braille readers. This can be supported by comparing the distribution of initial reading abilities for the subjects in this investigation (Figure 1) with a corresponding distribution for subjects from the preceding investigation. Although the ranges of the two distributions are comparable, the bulk of the subjects in the present investigation fall at lower reading abilities.

2. The relative positions of the various groups appear to show some consistency between the two investigations. From scanning the table of results (Table III), it can be seen that the .090"-.160"-.220" group ranked highest in this investigation. In the previous investigation it was in second place with respect to the five printing types used in the present experiment, but almost high enough for first place. The .090"-.160"-.220" group ranked lowest in this investigation and it was tied for lowest place in the previous investigation.

The correspondence between the two sets of ranks seems fairly strong. To this extent, the results of this experiment corroborate those of the first investigation.

TABLE IX

Answers to Questions At End of Experiment

Question 1: Is this Braille the same or different from what you are used to?

	Same	Different	Don't Know
090-160-220	9	9	2
090-140-220	7	11	2
090-123-220	7	11	2
080-160-220	9	11	0
080-123-163	1	18	1

Question 2: Are the dots in a character the same, farther apart, or closer than what you are used to?

	Same	Farther Apart	Closer	Don't Know
090-160-220	10	1	8	1
090-140-220	3	3	10	4
090-123-220	2	0	17	1
080-160-220	8	2	7	3
080-123-163	3	0	17	0

Question 3: Are the lines the same, farther apart, or closer than what you are used to?

	Same	Farther Apart	Closer	Don't Know
090-160-220	11	2	6	1
090-140-220	5	4	7	4
090-123-220	13	0	4	3
080-160-220	13	2	4	1
080-123-163	3	0	16	1

Question 4: Are the cells the same, farther apart, or closer than what you are used to?

	Same	Farther Apart	Closer	Don't Know
090-160-220	10	2	7	1
090-140-220	7	4	6	3
090-123-220	5	0	13	2
080-160-220	9	1	8	2
080-123-163	5	1	14	0

Question 5: Is this Braille the same, better, or worse than the Braille you are used to?

	Same	Better	Worse	Don't Know
090-160-220	10	5	4	1
090-140-220	7	2	10	1
090-123-220	7	0	12	1
080-160-220	8	3	8	1
080-123-163	2	2	15	1

DISCUSSION

This experiment has corroborated the results of the Meyers, Ethington, and Ashcroft (1) investigation in finding that standard Braille printing (the .090"-.160"-.220" combination) is read more rapidly than most other types of Braille printing. Out of the five types of Braille printing used in the present investigation, standard Braille was the most readable.

Standard Braille may be more readable than other types of Braille printing for either or both of two reasons: (1) it may be more readable because it combines superior printing characteristics; or (2) it may be more readable because it is the printing type (out of the five used) with which the subjects had previous experiences. Favorable printing characteristics or familiarization from past experience -- which of these accounts for the superiority of "standard Braille"? This question cannot be answered conclusively from the results of this experiment. To provide a conclusive answer, it would be necessary for different groups of blind persons to learn Braille reading on different types of Braille printing. This would rule out the factor of past experience which complicates interpretation from the results of the present experiment.

Would Braille readers, reading material other than standard Braille, gain in proficiency over a longer period? This experiment used only two fifty-minute reading periods. It is possible that in changing from standard Braille to other Braille printing results in a temporary reduction in reading proficiency. Whether the reduced proficiency is relatively permanent or only temporary, due to changed printing, cannot be determined from this investigation. An investigation using a larger number of reading sessions would answer this question.

The fact that a printing type (.090"-.140"-.220") other than standard Braille (.090"-.160"-.220") proved just as readable when data were adjusted so as to equalize statistically initial reading ability suggests that there is nothing inherent in standard Braille which makes it superior to other types.

The .090" dot spacing types are superior consistently to .080" dot spacings. The Meyers, Ethington, and Ashcroft investigation showed that .090" dot spacings were as effective as .100" dot spacings. Taken together, the results of both investigations indicate that dots within a Braille cell can be too closely spaced and that a critical value exists between spacings of .080" and .090".

The .080"-.123"-.163" was the least readable printing used in this experiment. This is the most compact, closely spaced printing used in the experiment. As pointed out in the introduction to this report, this combination would yield the largest number of Braille characters on a page and it would be economical commercially for this reason. But it is the combination (out of the five used) which was most difficult to read. It would appear that the printing is so closely spaced that reading efficiency is lost.

There are several kinds of close spacing: nearness of dots within the Braille cell; nearness of adjacent cells in a horizontal line of print; nearness of two lines of print. The consistent superiority of .090" over the .080" spacings suggests that spacing of dots within the cell may be the most important of these.

SUMMARY

In an investigation of the readability of Braille printing the five following types of Braille printing were used: (1) .090" (distance between dots) - .160" (distance between Braille cells in a line of print) - .220" (distance between lines of Braille print) - (2) .090"-.140"-.220"; (3) .090"-.123"-.220"; (4) .080"-.160"-.220"; (5) .080"-.123"-.163". A different group of twenty blind Braille readers was assigned to read each of these five types of printing. Each person was used for three sessions: a preliminary session for assessment of reading ability; two experimental sessions of fifty minutes each.

The results obtained indicated that the .090"-.160"-.220" (Standard Braille) and .090"-.140"-.220" combinations were read most rapidly, the .080"-.123"-.163" combination was read least rapidly. .090" dot spacings were consistently superior to .080" dot spacings (distance between dots within a Braille cell).

References

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